USDA United States Department of Agriculture

Forest Service

**Rocky Mountain Forest and Range Experiment Station**

**Southwestern Region**

General Technical Report
RM-GTR-295



# An Assessment of Forest Ecosystem Health in the Southwest



Illustrations: Mary Beath

**Dahms, Cathy W.; Geils, Brian W., tech. eds. 1997. An assessment of forest ecosystem health in the Southwest. General Technical Report RM-GTR-295. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 97 p.**

This report documents an ecological assessment of forest ecosystem health in the Southwest. The assessment focuses at the regional level and mostly pertains to lands administered by the National Forest System. Information is presented for use by forest and district resource managers as well as collaborative partners in the stewardship of Southwestern forests. The report establishes a scientific basis for conducting forest health projects, provides a context for planning ecosystem restoration, and contributes to the understanding of the physical, biological, and human dimensions of these ecosystems. Chapters describe Southwestern forest ecosystems of the past, changes since the Colonial Period, and the implications of those changes for the health of current and future forests. Opportunities, tools, and research needs for improving long-term sustainability of these forest ecosystems are also identified.

**Keywords:** ecosystem health, forest health, disturbance, ecosystem management, ecological processes.

*Publisher's note:* Most of this report underwent editorial review by Southwestern Region staff. The Station composed pages directly from copy supplied by Cathy W. Dahms and Brian W. Geils.

*Cover art by Mary Beath*

**July 1997**

USDA Forest Service
General Technical Report RM-GTR-295

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**Cathy W. Dahms and Brian W. Geils**

***Technical Editors***

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# PREFACE

This report was prepared by the Southwestern Forest Ecosystem Health Team. When first established, the team included representatives from the Rocky Mountain Forest Range and Experiment Station and each resource staff in the Southwestern Region. Participants either served as members of a core team or assisted with writing. An initial draft was completed in 1995 and reviewed. At the suggestion of various reviewers, we have significantly re-written and re-structured the original draft.

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We acknowledge Lane Eskew (Rocky Mountain Forest and Range Experiment Station) and Mary Zabinski (Southwestern Region) for their roles as managing editors. Joyce Patterson assisted with preparation of figures. The team also recognizes the valuable comments and useful critiques provided by the following individuals: William Block, Brent Botts, Arthur Briggs, Sally Campbell, James Cooper, W. Wallace Covington, James Crawford, John Dale, Leon Fisher, Alan Harvey, Roy Jemison, Charles Lennahan, Gus McPherson, Keith Menasco, Will Moir, Richard Reitz, Mert Richards, John Schmid, Lamar Smith, Peter Stewart, Walter Stewart, Dan Winner, Michael Wagner, as well as several anonymous reviewers.

Support for this project was provided by the Southwestern Region and Rocky Mountain Forest and Range Experiment Station (Ecology, Recovery, and Sustainability of Grassland and Riparian Ecosystems in the Southwest and Impact of Natural Ecological Disturbances on Western Conifers).

# CHAPTER 1: INTRODUCTION

"The most important characteristic of an organism is that capacity for self-renewal known as health. There are two organisms whose processes of self-renewal have been subjected to human interference and control. One of these is man himself. The other is land."
Aldo Leopold (1949)

## PURPOSE

This report documents an **ecological assessment**[1] of forest **ecosystem** health in the Southwest (Arizona and New Mexico). The assessment focuses at the regional level and mostly pertains to lands administered by the National Forest System in the Southwestern Region. Information is presented for use by forest and district resource managers as well as collaborative partners in the **stewardship** of these lands and resources. The report establishes a scientific basis for conducting **forest health** projects, provides a context for planning **ecosystem restoration**, and contributes to the understanding of the physical, biological, and **human dimensions** of these forests. Chapters describe Southwestern forest ecosystems of the past, changes since the Colonial Period, and consequences to **biodiversity**, **resilience**, **biotic integrity**, and human use. Opportunities, tools, and research needs for improving **ecosystem sustainability** are also identified.

## WHAT IS FOREST HEALTH?

The definition of forest health is controversial. The concept of health is well understood as applied to humans but may not be appropriate for ecosystems. Defining health in terms of **homeostasis**, whereby any change in condition represents a decline in health, fits humans well but not ecosystems. A human is an organism with a highly integrated physiology; survival requires precise regulation of internal temperature. An ecosystem, however, is a dynamic community of competing and evolving populations bound by common energy pathways and nutrient cycles. Although ecosystems display **stability**, they are not homeostatic organisms. Similarly, human health can be defined by the absence of disease from parasites, bacteria, and viral infections. But in ecosystems, herbivorous insects, parasitic plants, and decay fungi are essential members of the **biotic community** with important roles determining **ecosystem structure** and **function**. It is only when their numbers increase beyond a range of **historic variability**, persist at chronic high levels, or when **exotic species** are introduced into the ecosystem that these **disturbance** agents might be considered **indicators** of unhealthy forests. The difficulties of defining an optimal condition for ecosystem health, coupled with the lack of universally accepted indicators to measure ecosystem health, have led some scientists to conclude that the concept of ecosystem health is ecologically inappropriate (Wicklum and Davies 1995).

Although the analogy of forest health with human health is invalid, there are general concepts applicable to all complex dynamic systems that can be used to describe and assess their condition. Sustainability—a comprehensive, multiscale, measure of system organization, resilience, function, and productivity—is proposed as a more useful concept than stability or absence of disturbance (Costanza et al. 1992). This property accounts for the dynamic nature of ecosystems and their adaptability to disturbance. Expressed in terms of biodiversity, resilience, biotic integrity, and human use, sustainability can be described at different **scales** of an ecological **hierarchy** and for biotic communities of any species composition. Although there are no simple and inexpensive methods for assessing ecosystem health, progress has been achieved over the last decade in development of data collection methods, identification of appropriate indicators and indices, and construction of

*[1] Selected terms with technical meaning or special usage are initially presented in bold type and defined in the Glossary.*

diagnostic models. Defining and assessing the health of complex ecosystems is not easy, but it is not impossible.

For practical reasons, it may be unimportant to define forest health in other than "fuzzy" terms (More 1996). One of the strengths of the forest health metaphor is that people can relate to it (Rapport 1995). A consensus on the need for forest health is sufficient to bring together resource managers, lawmakers, and the public. Most people have an intuitive idea of what constitutes a **healthy ecosystem**; at least, they believe they can recognize an unhealthy one when they see it. Perhaps more than any other event, the Yellowstone Fire of 1988 drew attention to the health of America's forests. Images of other devastating wildfires were kindled by media exposure of the destructive Dude Fire in 1990 and the fatal Storm King Fire in 1994. After decades of successful fire suppression, did these catastrophic fires indicate something was seriously wrong? In 1994, the Forest Service contracted with Kaset International for an independent poll of U.S. residents to learn what the public valued from its forests and what were their concerns over resource management. Even though no definition of forest health was provided, respondents overwhelmingly identified healthy forests as important and their protection as a high priority.

Although a general concept of forest health may be enough to bring people together over specific issues, resource managers also need the ability to assess overall ecosystem health. Attempts to translate general concepts of ecosystem health into operational standards have resulted in definitions that either focus on ecosystem structures and functions or on the capability to provide for human needs. Kolb et al. (1994) reviews a number of definitions and categorizes these perspectives as ecosystem or utilitarian. Kolb et al. (1994) proposes that healthy forests are distinguished by four qualitative attributes:

1. the physical environment, biotic resources, and trophic networks to support productive forests during at least some **seral** stages,
2. resistance to catastrophic change and/or the ability to recover from catastrophic change at the **landscape** level,
3. a functional equilibrium between supply and demand of essential resources (water, nutrients, light, growing space) for major portions of the vegetation, and
4. a diversity of seral stages and **stand** structures that provide **habitat** for many native species and all essential ecosystem processes.

Within the Forest Service, the definition of ecosystem health and its integration into goals and activities has evolved since 1988 from three different sources—forest pest management, global change (fire and atmosphere), and **ecosystem management**. As a consequence of various national strategic plans and programs, the Forest Service mission, and regional assessments (Wickman 1992, Quigley 1992, O'Laughlin et al. 1993, Everett et al. 1994, Campbell and Liegel 1996, Clark and Sampson 1995), a consensus is emerging on how to combine the utilitarian and ecosystem perspectives and what standards to use for judging biodiversity, biotic integrity, resilience, and human use.

An early definition of ecosystem health developed from the forest pest management perspective. Forest health is a condition where biotic and abiotic influences on the forest (i.e., insects, diseases, atmospheric deposition, silvicultural treatments, harvesting practices) do not threaten management objectives for a given forest now or in the future (McIntire 1988). The initial plan of providing forest health through silviculture and integrated pest management (McIntire 1988) was revised and given specific goals in a new strategic plan (USDA Forest Service 1993a). Although the initial definition of forest health was retained, greater weight was given in the revised plan to ecosystem management and maintaining functioning communities of plants and animals, including species formerly considered as "pests." Nonetheless, the goals of planning, prevention, suppression, protection, monitoring, restoration, and exclusion still mostly reflected an entomology and pathology perspective. In a 1994 update (USDA Forest Service 1994c), three key indicators of forest health are identified as change in forest area, tree growth, and mortality. Forest health concerns focused on threatened tree species and damaging agents.

Based on two workshops in 1987 and 1988, the USDA Forest Service (1988) proposed a research program for assessing forest health and productivity in a changing atmospheric environment. This program focused on issues at a global scale, incorporated atmospheric and other ecosystem processes into consideration of forest health, and identified the need for large scale monitoring and ecosystem models. Concerns over atmospheric pollution and climate change, as well as various forest declines and pest outbreaks, spurred participation by the Forest Service in a broad cooperative program (USDA Forest Service 1994a) called Forest Health Monitoring (FHM). The FHM program was designed to estimate the status, changes, and trends in selected indicators of forest ecosystem conditions on a regional basis (statewide and larger). In particular, this program was given responsibility for **monitoring** and reporting on ecosystem health, including air pollution effects on forests and insect, disease, and other stressor effects on forest ecosystems at the regional scale. Surveys conducted under this program emphasized change in forest area, tree growth, mortality, and crown appearance and tree damage caused by insects, pathogens, and abiotic agents (e.g., see Campbell and Liegel 1996).

Since 1994 the official mission and vision of the Forest Service is described in terms of ecosystem management (USDA Forest Service 1994b, Thomas and Huke 1996). In this context, ecosystem management refers to the integration of ecological, economic, and social factors to maintain and enhance the quality of the environment to best meet current and future needs. The focus priorities for the agency are protection, restoration, sustainability, and organizational effectiveness (USDA Forest Service 1994b, Thomas and Huke 1996). An integration of biophysical and human dimensions is described for each of these priorities. Protection through an understanding of the roles of various disturbance agents ensures the health and diversity of ecosystems while meeting people's needs. Ecological restoration using **prescribed fire**, **thinning**, and other management tools improves the likelihood that future options for resource use are maintained. In addition to providing multiple benefits for people within the capabilities of ecosystems on National Forest System lands, the agency supports action that incorporates sustained economic, sociocultural, and community goals consistent with a shared vision of desired ecosystem condition (Interagency Ecosystem Management Task Force 1995). The fourth focus priority, organizational effectiveness, is achieved by using appropriate scientific information and involving diverse communities in making resource decisions. With these four priorities included in the meaning of ecosystem management, forest health (as a component of ecosystem management) gains an economic and social context. This context of the human dimension complements the ecological perspective provided by programs focused on vegetation condition and tree damage.

Although the Forest Service has not yet adopted an official definition of forest health, there is an interim definition which reflects the evolving ideas described above. Twery and Gottschalk (1996) propose:

> forest health is a condition wherein a forest has the capacity across the landscape for renewal, for recovery from a wide range of disturbances, and for retention of its ecological resiliency, while meeting current and future needs of people for desired levels of values, uses, products, and services.

This is the definition of forest ecosystem health accepted by the Southwest assessment team and used in this report. The philosophy of ecosystem management—looking at ecosystems as interacting systems rather than individual components, incorporating multiple spatial and temporal scales, and recognizing that ecosystem management incorporates the human dimension as well as the biophysical dimension—has profoundly affected the way the Forest Service addresses forest ecosystem health.

## ECOSYSTEM MANAGEMENT

Ecosystem management is the overall concept which determines the Forest Service approach to restoring and maintaining forest health (Thomas and Huke 1996). The principles of ecosystem management emerge from both a philosophical land ethic and from various legislative acts. Although other organizations have embraced ecosystem management with their own meaning and context, the Forest Service uses the following definition (Thomas and Huke 1996):

> ecosystem management is a concept of natural resources management wherein national forest activities are considered within the context of economic, ecological, and social interactions within a defined area or region over both short and long term.

The land ethic behind ecosystem management traces back to Leopold (1949) and his call for a stewardship that goes beyond treating the land as a commodity. Ecosystem management is a shift in focus from managing outputs of ecosystems to maintaining the structure and function of ecosystems through time and for the benefit of present and future generations. The application of ecosystem management in the Forest Service involves four principles—public involvement, an **ecological approach**, partnerships, and management based on sound science (Thomas and Huke 1996).

The public is a partner in ecosystem management because people are an inseparable part of ecosystems and ecosystem management itself is a human endeavor (Carr 1995). Leopold's (1949) land ethic is based on the observation that people's beliefs and perceptions about the land influence how they treat it and what they expect from it. An understanding of the human dimension is as significant as the physical and biological dimensions for explaining how current ecosystem conditions (e.g., health) came to be. Forest health issues stem from human activity, are brought to light because of human concerns, and are addressed through human ingenuity (Carr 1995). Aspects of the human dimension include past and present land use, myths and beliefs, socio-economic structure and processes, demographics, lifestyles, and expectations.

The ecological approach to management is based on the observation that ecosystems are organized and behave according to certain physical and biological principles. The biotic members of an ecosystem are connected and interdependent; this includes humans. Ecosystems are dynamic; attempts to maintain them in a static condition can result in violent reaction (e.g., attempts to remove all fires from some ecosystems result in more serious fires). The boundaries of these interdependent and dynamic ecosystems are defined by geology, climate, and biotic history, not by administrative convention. Ecosystems are organized in hierarchical patterns so that actions at one level can have consequences at another (e.g., global warming can induce local extinction of a species). To be successful, management must be adaptive, taking into account the productive capabilities of the ecosystem, its ability to change, and its response to manipulation.

Because ecosystems are nested into larger and larger, interconnected units that cross many administrative boundaries, collaborative partnerships are necessary to make good decisions based on sound science. Stewardship requires the cooperation of multiple, public stakeholders and among managers and scientists of many agencies and disciplines. The elements of collaboration are—jointly develop shared vision and common goals; share responsibilities to obtain common goals where appropriate; and jointly work to achieve common goals using each collaborator's experience (USDA Forest Service 1994d).

Ecosystem management is based on sound science. This requires an understanding of how ecosystems function, how they support and tolerate human use, and how policy and management affects the environment (Thomas and Huke 1996).

Ecosystem management is based on the legislative authority and responsibility of the Forest Service as provided in numerous public laws. Statutes include the Multiple Use-Sustained Yield Act (1960), the National Forest Management Act (1976), National Environmental Policy Act (**NEPA**, 1969), Endangered Species Act (ESA, 1973), and pollution control laws such as the Clean Water Act and Clean Air Act. Funding to implement ecosystem management is provided by annual appropriations, partial returns from timber sales as provided in the Knutson–Vandenberg Act (**K-V**, 1930), and numerous partnership programs.

Ecosystem management is also embraced outside the Forest Service. In 1993, the Society of American Foresters appointed a task force to produce a report on sustaining long-term forest health and productivity. The report contained 26 recommendations within four broad areas—advocating ecosystem management, integrating ecosystem management into educational programs, promoting ecosystem management research, and coordination among landowners and with the public. Although the report represented an evolution of thinking among some prominent Society members, it failed to adequately address differences in a number of regional issues. In 1996, a broader task force reported to the Society on these regional issues and the connection of forest health to landowner objectives.

## ADAPTIVE MANAGEMENT

The proactive approach of the Forest Service to restore and maintain healthy forests is adaptive management. The theory and practice of adaptive management has evolved over the last two decades through the works of Walters (1986), Holling (1978), and Lee (1993). One of the fundamental tenets of adaptive management is that ecosystems and people are unpredictable as they evolve together. Ecosystems change as do the people that attempt to understand and manage them. In addition, the understanding of ecosystem behavior is imperfect, and managers will never be able to completely predict responses to management activities. Adaptive management encompasses both deliberate experimentation to gain new knowledge (active adaptive management) as well as the ongoing process of using monitoring and inventory information to assess the effects of management actions on ecosystem health (passive adaptive management). Active adaptive management is a departure from traditional management in that it views management actions as experiments from which to learn. Implementing adaptive management experiments involves being explicit about expected outcomes, designing methods to measure responses, collecting and analyzing information to compare expectations to actual outcomes, learning from the comparisons, and changing actions and plans accordingly (USDA Forest Service 1995). Collaboration with research is essential to provide the expertise on designing adaptive management programs so that they can be monitored and evaluated. Passive adaptive management may seem a misnomer because it requires a very active program for monitoring and evaluation of project activities, as well as some aspects of management experiments. Particularly for effectiveness and validation monitoring, the monitoring must be designed as statistically sound and scientifically credible.

With adaptive management, specific treatment actions are determined using an ecological approach to implement land management plans on each national forest. Project-level analyses are done in the context of broader scale assessments that identified desired conditions for healthy, sustainable ecosystems. Desired conditions for sustainable forest management are identified using public participation and collaboration in consideration of local management objectives and local conditions. Desired conditions provide descriptions of the desired human dimensions and physical, biological characteristics to be achieved in an area over short and long time frames.

## RISE OF THE FOREST ECOSYSTEM HEALTH ISSUE IN THE SOUTHWEST

In many respects, the Forest Service, Southwestern Region was a pioneer in adopting a broad perspective of forest ecosystem health. The emphasis on ecosystem health at the regional level began in 1992 with the adoption of a series of initiatives to address forest health in specific, threatened, biotic communities, namely pinyon–juniper, riparian, and aspen. In 1993, initiatives for these communities were combined with those for the remaining forest communities as the Forest Health Restoration Initiative (USDA Forest Service 1993b) The goal of this program was to increase public awareness in forest ecosystem health, gain agency and public support, and begin the work of ecosystem restoration.

In 1994, the Southwestern Region developed a report on the human dimension of ecosystem management (USDA Forest Service 1994d). The report states that ecosystem management must include consideration of the physical, emotional, mental, spiritual, social, cultural, and economic well-being of people and communities within ecosystem capabilities. The report further observes that managerial decisions are in reality moral rather than technical judgements because they accommodate some people's values and not others. This underscores Carr's (1995) characterization of the complexity of these decisions and recognizes that there is rarely one correct solution for natural resource issues, only more or less useful solutions. The Southwestern Region and Rocky Mountain Forest and Range Experiment Station have several excellent collaborative projects. The Keystone Center (1996) highlights the **Malpais** Borderlands Group as a laboratory for demonstrating public involvement and collaborative techniques in the spirit of ecosystem management. The Yavapai Ecosystem Project received the Chief's Ecosystem Management Award for their innovative private-public cooperative strategy to sustain ecological integrity while still allowing economically viable ranching operations.

The Southwestern Region Leadership Team in partnership with the Rocky Mountain Station requested a detailed assessment of forest ecosystem health as an extension of the Forest Health Restoration Initiative. The Western Forest Health Initiative, announced in 1994, recommended development of regional assessments to describe the existing health of all Western Forests. This document details ecosystem health in forests of the Southwest.

# CHAPTER 2: ASSESSMENT APPROACH

"Under the concept of ecosystem management, planning is conducted using appropriate regional or area assessments of ecological, economic, and social effects and the interaction of these factors to enhance management..."

Jack Ward Thomas, 1995

This assessment examines the condition of forested ecosystems in Arizona and New Mexico and describes their past, present, and future at a regional planning and analysis scale. A variety of hierarchies exist to delineate these ecosystems on different characteristics (e.g., climatic, terrestrial, aquatic, and social), and the assessment team had considerable discussion on which hierarchy to use. Although it would be appropriate to structure this assessment by either **ecoregions** (terrestrial), river basins (aquatic), or economic-political units (social), required ecological information on past conditions, current status, and potential trends is generally not available by these geographic designations. Data are, however, available for Southwestern ecosystems by **life zone** characterized by biotic community. The assessment is therefore based on taxonomic categories of dominant vegetation; and differences in condition and response for geographic **provinces** are noted within discussions organized by biotic community.

The assessment uses guidelines in the draft National Framework for Integrated Ecological Assessments[2] and includes the following elements for Southwestern forests as a whole and for each life zone in particular:

1. A description of the current and historic composition, structure, and function.
2. A description of the abiotic and biotic events, including human actions, that contributed to development of the current condition.

These elements are incorporated into the assessment on the fundamental premise that human actions change ecosystems. Past, present, and future perceptions and beliefs influence ecosystems, just as ecosystems influence the physical, spiritual, cultural, and economic well-being of people. Before managers can attempt to integrate goals, perceptions, beliefs, and values into ecosystem planning, they must be aware of the origin and evolution of these human wants and needs. This topic is addressed in Chapter 3.

An historical perspective (element 1) establishes reference conditions for estimating how current ecosystems differ from ecosystems of the past. Historical characterizations also provide insights into possible future ecosystem development by identifying significant disturbance agents and regimes, vegetation patterns, environmental constraints, and the variability of biotic patterns and processes. Characterization of historic conditions in the Southwest during Native American and Spanish Colonial times is provided in Chapter 4.

During the Territorial Period following the war of 1848, came increasing levels of hunting, **grazing**, timber harvest, farming, irrigation, and building of towns, cities, and civil projects. The changes in forest ecosystems (element 2) that resulted from new resource demands and management regimes are described in Chapter 5.

An summary of current ecosystem conditions is provided in Chapter 6. The indicators of forest health are: 1) biological diversity, 2) biotic integrity and resilience, and 3) human needs and uses. The assessment team believes these three indicators accurately reflect the biological, physical, and human dimensions required for sustaining ecosystems. Biological diversity is a frequently used measure of ecosystem complexity; reduction of ecosystem complexity is generally considered detrimental to ecosystem health. Biotic integrity, as used in this report, refers to the ability of a community

*[2] Unpublished document outlining a national strategy for integrated ecological assessments prepared by a bio-physical team (chaired by Eric Hyatt, EPA) and a human dimensions team (chaired by Isobel Sheifer, NOAA).*

to recover and maintain system processes within historic variability. Resilience to disturbance insures maintenance of biodiversity and biotic integrity. Human needs and wants reflect not only the economic needs of society and communities, but also their cultural, spiritual, and aesthetic aspirations.

Actions the assessment team believes could improve forest health are described in the remaining chapters. Management opportunities are discussed in Chapter 7; specific tools are covered in Chapter 8; and research needs are identified in Chapter 9.

## ECOSYSTEM SCALE, HIERARCHY, AND CLASSIFICATION

One of the differences between ecosystem management and previous management approaches is the recognition of the importance of scale and **hierarchy**. Ecosystems are defined by their boundaries, and depending on one's perspective could be a pond, a small **watershed**, a major river basin, or even the whole biosphere. Ecosystems can be viewed both as a landscape of similarly scaled stands (like a patchwork quilt) and as an ordered nesting of patches within stands, stands within forests, and forests within regions (a hierarchical organization). The concept of scale applies not only to ecosystem structure but also to ecosystem processes (Figure 2.1). These processes act over distinct and characteristic spatial and temporal scales and determine ecosystem structure (Holling 1992). These processes may be local such as tree fall, or landscape such as **habitat fragmentation**, or rapid such as plant re-establishment and **succession** after fire, or slow such as soil development. Some processes, such as bark beetle outbreaks, are particularly relevant to ecosystem health because they occur at spatial and temporal scales which correspond to those with human interest and importance (Holling 1992). Identification of scale and hierarchy are necessary to provide the proper context for ecosystem description and analysis.

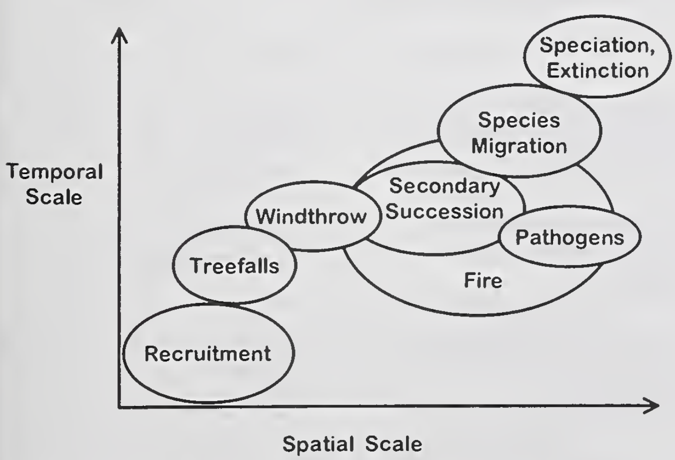


**Figure 2.1 Spatial and temporal scales of some common ecological processes.**

The complexity of describing ecosystems over a range of scales and accounting for their hierarchical structure is handled through classification. Although classification is a challenging task, it produces very useful management tools. Ecological classifications range from relatively simple, using few characteristics such as species composition, to more comprehensive, integrating multiple environmental characteristics such as climate, topography, soil, and vegetation. Classification systems identify the relative degree of similarity among ecosystems and arrange these into groups ranked by spatial scale or hierarchy. One of the best uses of ecological classification is for stratifying the land base into units with similar productive capacities and responses to management. Classifications also help in the conduct of inventories for rare species (or other ecosystem elements) because these species are usually associated with a single or definable group of ecosystems. When classification is combined with a Geographic Information System (**GIS**), the pair becomes a powerful tool for analysis and display of spatial data. Ecological classification systems are developed from either a geographic or taxonomic approach.

The geographical approach (Bailey 1996) is a top-down method whereby the classifier begins with a large land area and splits it into smaller units with similar vegetation, landform, or other attributes. This method, also called regionalization, is a simultaneous process of classification and mapping with the objective of identifying internally homogeneous map units. Because the method is used at a broad scale, map units often contain ecologically significant inclusions such as riparian corridors that do not fit well into the map topology. The best use of regionalization is classification and mapping at broad scales—dividing continents into domains (based on broad climatic zones), domains into divisions (based on regional climate), divisions into provinces (based on landforms, altitudinal zones and plant formations), provinces into sections (based on physiography) and sections into subsections (based on surficial geology). The National Framework of Ecological Units (Table 2.1) based on terms defined by Bailey (1995) is an excellent example of the geographical approach.

In Bailey's (1995) approach, landtypes are divided into landtype phases or aggregated into landtype associations for landscape scale planning and analysis. At these detailed levels, **forest** and **woodland** stands as well as linear **riparian ecosystems** are recognized. Because these units can be observed on the ground, they are especially meaningful to managers and the public. The phase, landtype, and association are the smallest recognized divisions in the hierarchy of the National Framework of Ecological Units (Table 2.1). Landtype and phase (land units) are useful for project planning and analysis and link to landscape units. Landtype associations (landscape units) are useful in forest planning and tier to the subregional units described by Bailey et al. (1994).

Geographic classification is useful for strategic planning at regional or statewide levels. For planning and management at watershed, forest, and project levels, however, a fine-grain, taxonomic classification is required. The taxonomic approach (Pfister and Arno 1980) is a bottom-up aggregation of individual, sampled sites which represent the population of all sites within an area and are intensively measured for a wide variety of ecological attributes. Aggregation uses multivariate statistical analysis to determine the similarity between units; mapping is a separate activity. The basis for classification may be potential or **climax** vegetation (**habitat type**) as developed by Daubenmire and Daubenmire (1968) and illustrated for Southwestern forests and woodlands by Stuever and Hayden (1996). Although vegetation alone well integrates numerous ecological and environmental factors, various other taxonomic systems explicitly use climatic, physiographic, edaphic, and vegetation data. An example of this approach is the Ecological Land Classification Framework for the United States (Driscoll et al. 1984).

The comprehensive ecological classification system used in the Southwestern Region for analysis and planning is the Ecological Land Classification Framework for the United States (Driscoll et al. 1984) based on the Modified Ecoclass System. From this framework, the Southwestern Region developed the Terrestrial Ecosystem Survey (**TES**) procedures for

**Table 2.1 National Framework of Ecological Units for planning and analysis by the National Forest System.**

| Planning and analysis scale | Ecological Units | Purpose, objectives, and general use | General size range |
|---|---|---|---|
| Ecoregion | | Broad applicability for modeling and sampling. | 1,000,000s to 10,000s of square miles. |
| Global | Domain | Strategic planning and assessment. | |
| Continental | Division | International planning | |
| Regional | Province | | |
| Subregion | Section | Strategic, multi-forest, statewide and multi-agency analysis and assessment. | 1,000s to 10s of square miles. |
| | Subsection | | |
| Landscape | Landtype Association | Forest or area-wide planning, watershed analysis. | 1,000s to 100s of acres. |
| Land Unit | Landtype | Project and management area planning and analysis. | 100's to less than 10 acres. |
| | Landtype Phase | | |

Terms and concepts developed by Bailey (1995); table adapted from unpublished work by National [Forest Service] Ecomap Team.

classification, mapping of ecological units, and direction for interpreting the relationships of soil, vegetation, and climate. Two scales are available for mapping of ecological units. TES units are mapped as polygons at 1:24,000 and correspond to the land unit scale (Table 2.1). General Ecosystem Survey (Carleton et. al 1991) units are mapped at 1:250,000 and correspond to the landscape scale (Table 2.1). These units are meaningful to resource managers and the public in that these units are observable spatial features that repeat themselves across the landscape. Managers can use these units to evaluate cause and effect relationships among management scenarios. The landscape scale and scales immediately above and below in the National Framework (Table 2.1) are those most appropriate for a regional assessment of forest ecosystem health.

## FORESTED PROVINCES OF THE SOUTHWEST

Ecoregion provinces designate regional geographic areas with similar climates and landforms (Bailey 1995). Within the National Hierarchical Framework of Ecological Units, the province is the appropriate scale for broad-level, strategic planning and assessment. The seven provinces (Bailey et al. 1994) mapped for the Southwest (Figure 2.2) are:

1. American Semi-Desert and Desert Province,
2. Arizona-New Mexico Mountains Semi-Desert - Open Woodland - Coniferous Forest - Alpine Meadow Province,
3. Chihuahuan Semi-Desert Province,
4. Colorado Plateau Semi-Desert Province,
5. Great Plains - Palouse Dry Steppe Province,
6. Southern Rocky Mountain Steppe - Open Woodland - Coniferous Forest - Alpine Meadow Province, and
7. Southwestern Plateau and Plains Dry Steppe and Shrub Province.

Because this is an assessment of forest and woodland ecosystems, the American Semi-Desert and Desert, the Chihuahuan Semi-Desert, and the Southwestern Plateau and Plains Dry Steppe and Shrub Provinces are excluded from further discussion. Provinces (and more specifically sections and subsections) delimit areas with like interactions among land units and which consequently form landscapes characteristic of the region. For example, because of differences in climate, landform, and history, succession proceeds differently in the Southern Rocky Mountain Province than in the Colorado Plateau Province. Differences in succession lead to the formation of regionally distinct landscapes, even though the same species are present in both provinces. Bailey (1995) describes the Southwestern provinces which include forest and woodland communities.

### Arizona–New Mexico Mountains Semi-Desert – Open Woodland – Coniferous Forest – Alpine Meadow Province

The geomorphology includes mountains, hills, plains, and scarps across central Arizona, and western and southern New Mexico. The elevation starts at 6,000 feet and goes up to 12,500 feet. Precipitation ranges from 12 to 35 inches annually. Potential vegetation includes pinyon (certain *Pinus* spp.), juniper (*Juniperus*), Gambel oak (*Quercus gambelii*), ponderosa pine (*P. ponderosa*), white fir (*Abies concolor*), and Douglas-fir (*Pseudotsuga menzesii*). Aspen (*Populus tremuloides*) is an occasional species. The primary abiotic disturbance is fire; and the primary anthropological land use is forest management, including recreation, timber, aesthetics, and wildlife habitat. Portions of the Tonto, Coconino, Apache–Sitgreaves, Lincoln, Cibola, and Santa Fe National Forests are included in this province.

### Colorado Plateau Semi-Desert Province

This province contains lower tablelands in Arizona and New Mexico; the Colorado River is the region's only large stream. The geomorphology of this province includes canyons, cliffs, scarps, plateaus, hills, and mountains. The elevation ranges from 3,000 feet to 7,000 feet. Annual precipitation ranges from 6 inches to 25 inches. In the lowest vegetation zone are arid grasslands and shrubs; sagebrush (*Artemisia*) is common over large areas. The woodland zone is the most extensive; pinyon and juniper are the dominant vegetation. The montane zone extends over the high plateaus and mountains; trees include ponderosa pine, Douglas-fir and aspen. Abiotic disturbances include wind, floods, drought, and fire. The principal anthropological land use is production of **forage** for

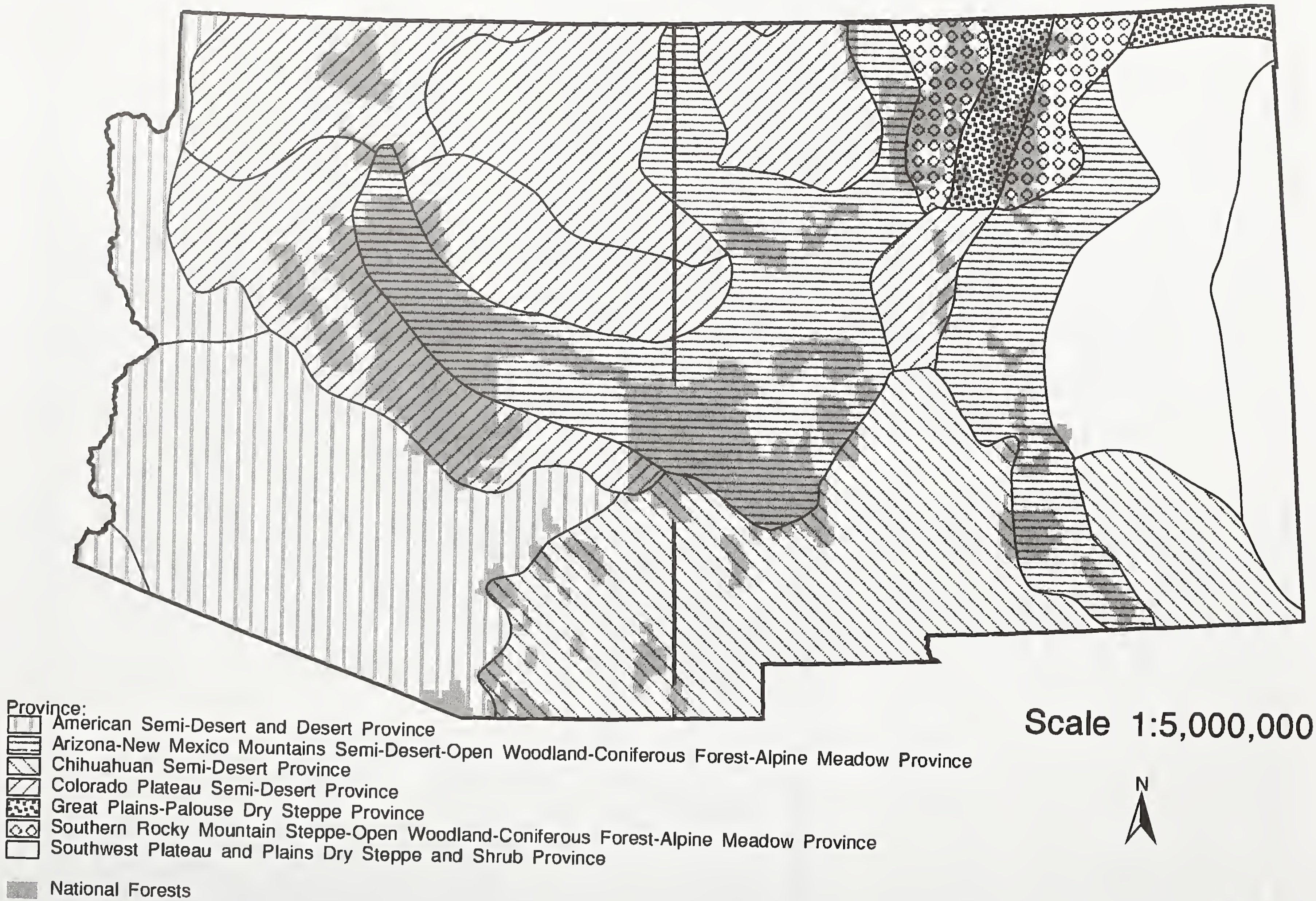


Figure 2.2 Provinces of Arizona and New Mexico; sections within provinces are delimited with solid lines; National Forests are indicated by solid fill pattern.

livestock **grazing** and **browsing**. Portions of the Tonto, Prescott, Kaibab, Coconino, and Apache-Sitgreaves National Forests are included in this province.

### Southern Rocky Mountain Steppe – Open Woodland – Coniferous Forest – Alpine Meadow Province

Landforms include mountains and valley plains of northern New Mexico. The elevations range from 7,500 to 14,000 feet. Annual precipitation ranges from 24 to 28 inches. Ponderosa pine, Douglas-fir, aspen, subalpine fir (*Abies lasiocarpa*) and Englemann spruce (*Picea engelmannii*) are common tree species. The primary abiotic disturbance is fire. Recreation, mining, and ranching are important land uses. This province includes significant portions of the Carson and Santa Fe National Forests.

### Great Plains – Palouse Dry Steppe Province

Landforms include valley, lowlands, and elevated plains and hills in northern New Mexico. Elevation ranges from 6,800 to 8,800 feet. Precipitation varies from 6 to 8 inches annually, and less than half of the precipitation falls during winter. Various species of **forbs** and grasses (**graminoids**) are found in the uplands; cottonwoods (*Populus*) and willows (*Salix*) along riparian corridors form the only forests in the province. Farming and ranching are the primary land uses. This province includes portions of the Carson and Santa Fe National Forests.

## LIFE ZONES OF THE SOUTHWEST

The General Ecosystem Survey (Carleton et al. 1991) groups Southwestern ecosystems into life zones characterized by biotic community types including desert, grassland, chaparral, evergreen oak woodland, coniferous woodland, ponderosa pine, mixed conifer, spruce–fir, tundra, and riparian wetlands. Because this is an assessment of forest, woodland, and associated riparian ecosystems, desert, grassland, chaparral, and tundra life zones are excluded from further discussion. The concept of a life zone is derived from a taxonomic classification system described first by Merriam (1898), revised by UNESCO (1973), and applied in the Southwest by the Terrestrial Ecosystem Survey. The General Ecosystem Survey life zones (Table 2.2) can be cross-referenced to the biotic communities described by Brown and Lowe (1977, 1980) and Brown (1994). Aspen is a component of the montane forest found mostly in the mixed conifer zone but also in the ponderosa pine and the spruce–fir zones. Riparian wetlands occupy little area but like aspen perform special and very important ecological and landscape functions within their life zone. Because of their uniqueness and value, aspen and riparian wetlands are treated here along with evergreen oak and coniferous woodlands, ponderosa pine, mixed conifer, and spruce–fir forests as forest biotic communities of the Southwest (Figure 2.3).

A specific ecosystem can be located with reference to a geographic province; and if it is defined by the dominant vegetation, it can also be associated with other ecosystems of similar biotic composition (life zone). Whereas the province scale is the correct perspective for examining landscape dynamics, the life zone is the appropriate scale for describing aspects of community development such as disturbance regime and successional pattern. Every ecosystem is a unique entity with its own particular history, composition, structure, and potential. Although ecosystems of a common life zone tend to respond in similar ways, each is different. Some of this difference can be explained by location within a landscape and

**Table 2.2 Correspondence between General Ecosystem Survey Life Zones and Southwestern Biotic Communities.**

| Life Zone | Biotic Community |
|---|---|
| Evergreen oak woodshedwatershed | Madrean evergreen woodland |
| Coniferous woodland | Great Basin conifer woodland |
| Ponderosa pine and mixed conifer | Rocky Mountain/Madrean montane coniferous forest |
| Spruce-fir | Rocky Mountain subalpine coniferous forest. |

Life zones defined by Carleton et al. (1991); biotic communities described by Brown and Lowe (1977, 1980) and Brown (1994).

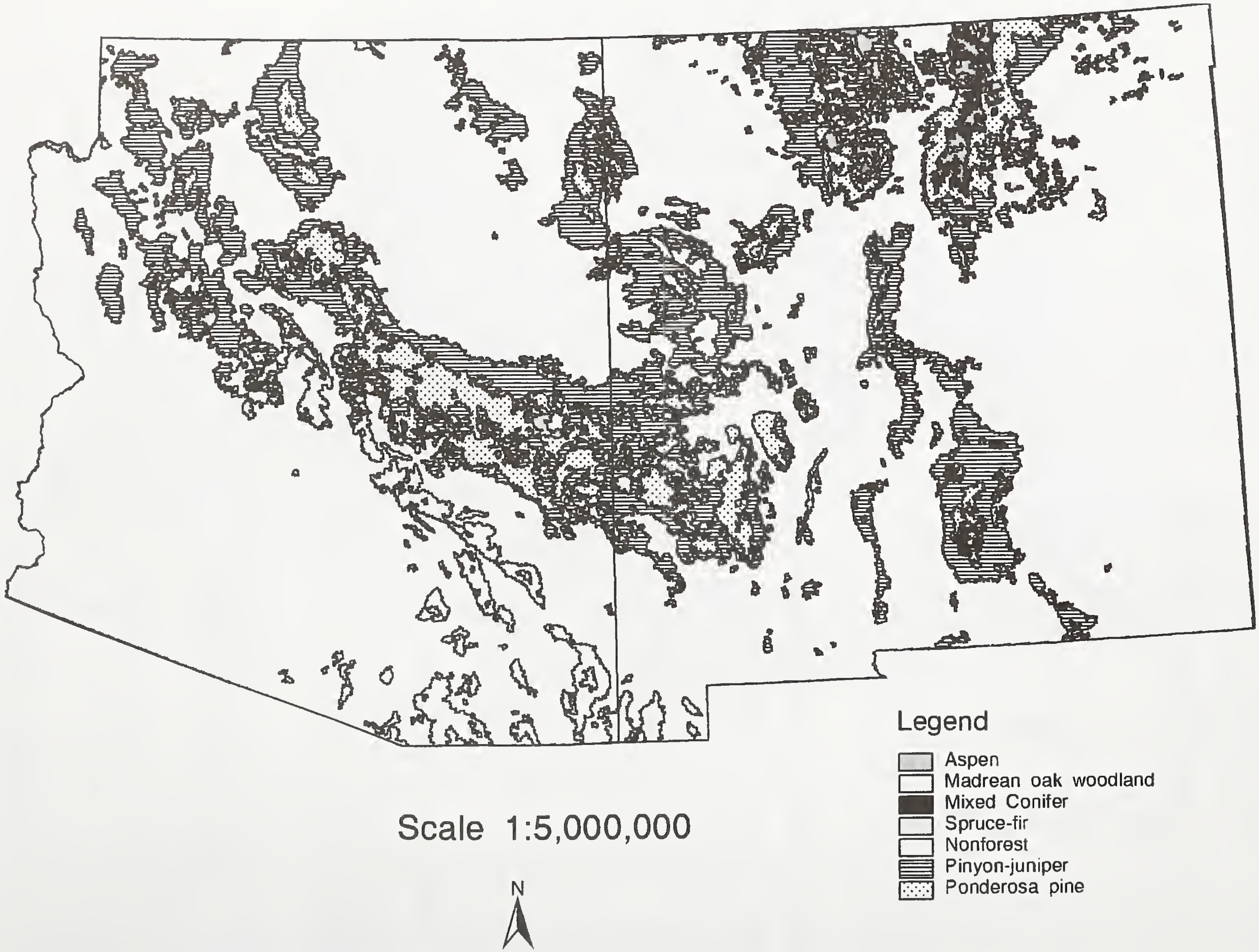


Figure 2.3 Life zones of Arizona and New Mexico as characterized by biotic communities.

province. Because most of the available information for past and current ecosystems is cataloged or identified by life zone, this assessment primarily describes Southwestern ecosystems by life zone and notes differences by province where they are known.

### Evergreen Oak and Coniferous Woodlands

Woodlands generally include evergreen oak and conifer species that occupy certain areas along an elevational gradient from low-elevation desert shrub/grasslands and short-grass prairies to high-elevation montane coniferous forests of ponderosa pine and Gambel oak. Oak woodlands occur within the range of 4,000 to 9,000 feet elevation. Gambel oak occurs at higher elevations, and wavyleaf oak (*Quercus undulata*) occurs either below Gambel oak or intermingled with it in a transition zone. Woodlands were used extensively by prehistoric and historic populations for habitation and subsistence. Uses today include grazing, **fuelwood** harvest, and recreation.

Evergreen oak woodland, characterized by wet summers and mild winters, extends from the Sierra Madre of Mexico into southeastern Arizona and southwestern New Mexico. In the United States, a variety of oak species such as Emory oak (*Quercus emoryi*), Arizona white oak (*Q. arizonica*), Mexican blue oak (*Q. oblongifolia*), gray oak (*Q. grisea*), silverleaf oak (*Q. hypoleucoides*), and netleaf oak (*Q. rugosa*) are found in conjunction with the following Madrean pine species—Apache pine (*Pinus engelmannii*), Chihuahua pine (*P. leiophylla* var. *chihuahuana*), and Arizona pine (*P. arizonica*) (Brown 1994).

Pinyons and junipers, together or alone, dominate coniferous woodland communities. These woodlands occupy approximately 23 million acres in New Mexico, about 13 percent of which are on national forest lands, and 4.1 million acres in Arizona, 34 percent on national forest lands. The pinyons include *Pinus edulis*, the most common pinyon pine throughout the type, border pinyon (*P. discolor*), and Arizona singleleaf pinyon (*P. californarium* subsp. *fallax*). Junipers are frequently found at lower elevations than pinyons and typically occupy sites with deep soils. The most common junipers in the Southwest are one-seed juniper (*Juniperus monosperma*) found in central and southern New Mexico and much of Arizona below the Mogollon Rim, the Rocky Mountain juniper (*J. scopulorum*) in the higher and colder woodlands of northern New Mexico and Arizona, Utah juniper (*J. osteosperma*) in northwestern New Mexico and northern Arizona, and alligator juniper (*J. deppeana*) associated with the Madrean woodlands of southern Arizona and New Mexico (Brown 1994, Gottfried 1992).

### Ponderosa Pine

Ponderosa pine (yellow pine or blackjack pine) is found from 6,500 to 8,000 feet elevation. At lower elevations, the ponderosa pine forest meets woodlands and at higher elevations transitions into the mixed conifer zone. Ponderosa pine forests of central and northern New Mexico and Arizona cover about 8.4 million acres. The predominant form throughout the Southwest is the three-needled, Rocky Mountain ponderosa pine (*P. ponderosa* var. *scopulorum*). In lower elevations of southern Arizona, however, the five-needled, Arizona pine is more common. Other species associated with ponderosa pine at low elevations are Gambel oak and New Mexico locust (*Robina neomexicana*); at high elevations associates are southwestern white pine (*Pinus strobiformis*), Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca*), Rocky Mountain white fir (*Abies concolor* var. *concolor*), and quaking aspen (*Populus tremuloides*) (Brown 1994). Uses include timber harvest, grazing, camping, and other types of recreation offering cool relief from hot urban areas.

### Mixed Conifer

Mixed conifer forests dominated by Douglas-fir, white fir, and blue spruce (*Picea pungens*) occur at elevations from 8,000 to 9,500 feet. There are about 1.5 million acres of mixed conifer forest in the Rocky Mountain and Madrean montane forests of southern Colorado, New Mexico, Arizona, and the Sierra Madre Occidental of Mexico (Brown 1994). Ponderosa pine, southwestern white pine, aspen, and a number of other tree species may occur in these forests. Uses are similar to the ponderosa pine community.

### Spruce–Fir

Spruce–fir forests are found at high, subalpine, elevations in the Southwest from approximately 8,000 feet to over 12,000 feet. Spruce–fir forests are typically restricted to areas receiving more than 25 inches of precipitation from winter snows and summer thunderstorms. The predominant spruce is Engelmann spruce which is found as far south as the Pinaleno Mountains in Arizona and the Sacramentos in New Mexico. The co-dominant species is subalpine fir (*Abies lasiocarpa*). Some populations of subalpine fir possess a distinctive outer cortex and are called corkbark fir (*A. lasiocarpa* var. *arizonica*). Small stands of aspen or blue spruce are found within the spruce–fir forest (Brown 1994). Uses include wilderness recreation, skiing, and the enjoyment of high places. Mountain peaks have special cultural and religious significance for many Southwestern Indian tribes.

### Aspen

Quaking aspen occurs at elevations above 6,000 feet as small, transient patches in ponderosa pine, mixed conifer, or spruce–fir forests. There are close to 500,000 acres of aspen in the Southwest, seventy-five percent in northern New Mexico and the remainder in the Mogollon Rim-White Mountains of Arizona (Brown 1994). Aspens can reproduce by cloning from an established root system and establish a new stand of trees quickly after a fire or other disturbance. Aspens, however, are intolerant of shade and eventually lose out to competition when they become overtopped by re-invading conifers. Aspen stands are especially valued for their scenic quality and use by traditional communities.

### Riparian Wetlands

Riparian wetlands including **cienegas** make up less than 2 percent of the land of New Mexico and Arizona, but they are the most biologically diverse and productive ecosystems in the Southwest. Over 65 percent of Southwestern animals depend on riparian habitats during all or part of their life cycles. Millions of Southwestern residents use these areas for recreation and agriculture. The most important species of Southwestern riparian wetlands are the Fremont cottonwood (*Populus fremontii*) and the narrowleaf cottonwood (*P. augustifolia*) (Brown 1994).

# CHAPTER 3: THE HUMAN DIMENSION OF THE LAND

"The replacement of Indians by predominantly European populations in New England [and the West] was as much an ecological as a cultural revolution, and the human side of that revolution cannot be fully understood until it is embedded in the ecological one."

William Cronon (1983)

The premise of this chapter is that the land, the biological processes, and the physical presence of all living and non-living things are reality; we humans are part of that reality. Where does the intellectual human stand in relation to this definition of reality? As we perceive the non-human through our numerous cultural filters, we create the ideas of nature, wilderness, and wildness; we re-create the animals, plants, sky, and water by naming them and placing real and imagined boundaries around them.

To understand the meaning of natural phenomena and one's own relation to nature, people create myths. The word "myth" is not used here in a negative sense as a contrast to "real." Rather, myth stands for the cultural glue that binds people of like communities over time. Although myths evolve over generations, they are usually based on real people, places, and events. Myths become reality to the individuals and groups who create them. There is physical reality, and there is cultural reality. The latter consists of artificial codes, ideological identities, and objects re-invented by recombination and juxtaposition (Clifford 1988). Myths are shared within **communities of interest** and **communities of place**.

### READING MYTHS

Solomon (1988) defines semiotics as the analysis of ordinary objects for signs of hidden cultural interests. His four principles of semiotics are:

1. Always question the "common sense" view of things, because "common sense" is really "communal sense," i.e., the habitual opinions and perspectives of the tribe.
2. The "common sense" viewpoint is usually motivated by a cultural interest that manipulates consciousness for ideological reasons.
3. Cultures tend to conceal their ideologies behind the veil of nature, defining what they do as "natural" and condemning contrary cultural practices as "unnatural."
4. In evaluating any system of cultural practices, one must take into account the interests behind it.

Why is semiotics relevant to forest ecosystem health? Perceptions of wildlands continue to "re-create" wildlands. Science, environmentalism, wise-use, conservation, and popular culture interpret nature according to the mythologies of its own interest group. Behind all of these mythologies lies the physical reality of wildlands. Agencies concerned with forest ecosystem health must sift through the cultural constructs to find core reality. The Forest Service cannot manage mythological wildlands.

Long before the arrival of Europeans to the New World, Native Americans interpreted their physical and mythic ties to the land through oral traditions and ceremonies. Guided by a sense of oneness with the earth (Allen 1986), they sought to balance their lives with all things through reciprocity, giving back to the earth as they took food and shelter from it. Ceremonialism was geared to seasonal change; the relation of the rising and setting of the sun, moon, and stars to special features on the landscape signalled new religious cycles. Mountains were places where sacred energy could be received from spiritual beings (Leeming 1990). The Southwestern landscapes in which Native Americans lived were sacred to them.

Questing for gold, commerce, and converts, the Spaniards moved into the New World in the 16th century. Stories of Aztec and Inca gold hordes fueled imaginations and lured expeditions into what would later be named the Southwest. Attended by Fray Juan de Padilla, Coronado came to the New World to find the fabled wealthy and intellectually perfect Seven Cities of Antilla and reunite them with the Christian world (Kessell 1987). Although the golden civilizations of Mexico and Peru were never discovered in the northern lands, future converts to Catholicism for the greater glory of God and subjects and new lands for the King of Spain were found (Crosby 1972). For Spanish colonists, the Southwest was a harsh and inhospitable land, remote beyond compare (Kessell 1989). It was, however, a land granted to them forever by their King, and as such it took on the deep cultural meaning of the Spanish homeland.

Over 60 years after Coronado's expeditions in the Southwest, English settlements on the other side of the continent were thriving on materials grown in the New World and exported to Europe. Production of plants native to the Americas and plants and animals of European origins were the basis of this commerce (Crosby 1972). By 1607, English enthusiasm for New World settlement was fueled by the opportunity for religious freedom and the potential for commerce between England and these new settlements (Miller 1956). The wilderness was not a passive concept to the new American settlers; it represented an historical challenge. From wilderness, American farmers could build a life of independence, freedom, and fulfillment—the Jeffersonian Arcadia, an ideal garden. As Tocqueville noted from a visit to America, "...the wilderness was precious to most Americans chiefly for what could be made of it—a terrain of rural peace and happiness" (Marx 1964).

In the Southwest, these and many other contrasting mythologies came together in conflict and uneasy accommodation during the 17th, 18th, and 19th centuries as the territory passed from Spanish to Mexican to American rule. Mixing mythologies is the core of American life, and many mythologies relate to American perceptions of wildlands and wild processes. Preceptions have driven and continue to drive wildland management because people cannot be separated from the land and their myths of it.

## SOME POPULAR AMERICAN LAND MYTHS

### There Was No Land Management in America Before Europeans Arrived.

To what extent lands of North America were managed by American Indians before Columbus arrived in the Americas is not precisely known. Nabhan (1995) states,

> "...we are often left hearing the truism, before the White Man came, North America was essentially a wilderness where the few Indian inhabitants lived in constant harmony with nature ... even though millions of people speaking over two hundred languages variously burned, pruned, hunted, hacked, cleared, irrigated, and planted in an astonishing diversity of habitats. And many people imagine that these indigenous peoples lived in some static homeostasis with all the various plants and animals they encountered."

Although Nabhan may have overstated the scale of this impact, his basic point is well taken. Although hunter–gatherers who harvested seasonal plant and animal resources may have affected animal populations more than their habitats, this was not true for all cultures. Sedentary people, agriculturalists, most assuredly modified the landscapes around them, whether living in groups of ten or over a thousand.

Before the horse was brought to the New World, land use was probably concentrated in localized areas around settlements. In the arid Southwest, settlements by native peoples or colonists concentrated close to the limited water sources, and exploited shallow, nutrient-poor soils for agriculture. Near these settlements, trees became building materials and firewood; and game was a major food source (Kohler 1992). How far might a resident of a 100-year-old village of 1,000 people have walked to find new fields, firewood, or game—5 to 10 miles?

Some scholars suggest that European diseases carried by the first explorers had an early and devastating effect on the native populations of eastern North America. By the time colonists and settlers first saw these "new lands," they may have been abandoned and untended for 50 to 200 years. What the colonists may have discovered was the regeneration of previously managed forests (Nabhan 1995, Cronon 1983). English visitors noted that large sections of the southern New England forest were burned twice a year by Indian villagers. According to Thomas Morton (Cronon 1983):

> "The Savages are accustomed to set fire of the Country in all places where they come, and to burne it twize a yeare, viz: at the Spring, and the fall of the leafe, [a practice that produced] open and parklike [forests where there were] more ground fires than forest fires..."

Unlike the East and other parts of the West, this degree of burning was not documented for Southwestern native cultures. Given the frequency of natural fires, deliberate burning probably would not have been necessary (Swetnam and Baisan 1996). It is likely, however, that fire was used on a local scale for specific purposes. The Europeans who had not witnessed American Indian forest and grassland management would probably not have expected or recognized the land as having been managed.

### American Wildlands are "Pristine" and "Untrammeled."

As discussed above, American lands were far from untouched when Europeans arrived in the New World. The Europeans brought with them overwhelming forces of change. From the standpoint of the land, however, the most profound invasion force to enter North American was not clad in armor but in fur, hide, feathers, shells, rinds, and husks. Within 200 years, much of the biology of North America was irrevocably altered by the cattle, oxen, horses, sheep, pigs, rats, birds, plants, insects, and fungi brought from the Old World.

Overgrazing coupled with continued burning of grasslands provided fertile ground for exotic plants and reduced more palatable native species. Many plants were purposely introduced by Europeans to provide foods to which they were accustomed and ornamentals that reminded them of home (Crosby 1972). The increase in crop plants like wheat, rice, and fruits, coupled with corn and potatoes, provided a rich food base that could support greater numbers of settlers. Using oxen, the rich sod of grasslands and meadows could be broken up to allow more intense cropping, large food supplies, and even more people (Crosby 1972).

By 1800, the flora and fauna of New England were very different from the land described in the journals of early colonists. In southern New England, beaver, deer, turkey, and wolves were near to extinction; hordes of cattle overgrazed lands opened by intensive burning; native grasses were striped off and soils desiccated. Once constant streams dwindled or disappeared as forests were removed (Cronon 1983). By the 1830s, machines began to assist humans in the reshaping of landscapes (Marx 1964).

Southwestern lands were not spared intensive use. In the 17th century, Spanish demands for tribute compelled the Pueblo Indians of New Mexico to intensify agricultural production by expanding their irrigation farming. In addition to an array of domestic livestock (sheep, goats, cattle, horses, mules, hogs, chickens) and new crops (wheat, barley, oats, onions, lettuce, watermelon, fruit trees), the Spanish also introduced native Mexican Indian crops such as tomatoes, chiles, cultivated tobacco, and new varieties of corn and beans. These introduced species along with the introduction of metal tools had a significant impact on native flora, fauna, and soils in the Southwest (Wozniak 1995, 1987).

Early livestock use had an effect in the Southwest even before the later 1800s. By 1870, the sheep population in New Mexico increased to 619,000. By the 1880s, nearly 5 million sheep were grazing in New Mexico, and this number did not decrease to 3.5 million until after the turn of the century (de Buys 1985). Because sheep graze higher up on steep slopes than cattle, their impact on fragile mountain soils is more destructive and eventually leads to flooding (de Buys 1985). The number of cattle in New Mexico increased from 148,000 in 1870 to 1.32 million in 1890; in Arizona during the same period, the number of cattle increased from 249,000 to 970,000. As trampled and naked soils heated up without adequate plant cover, cool-season, perennial, native grasses could not reestablish and were sparsely replaced by annual weeds from southern deserts. The productivity of most northern New Mexican land was lost during this time of extreme use (de Buys 1985). Arroyo formation, long considered a natural, visual trademark of the Southwest, may have been accelerated by a combination of natural climatic fluctuation and overgrazing (Hastings and Turner 1965, Cooke and Reeves 1976).

With the best of intentions, people introduced exotic plants into the Southwest to restore degraded natural areas. Saltcedar (*Tamarix ramosissima*), for example, was introduced to hold soils on floodplains left bare from overgrazing; and Russian-olive (*Elaeagnus augustifolia*) became a favorite landscaping plant because it thrives in arid landscapes with little rainfall. Contemporary diversity of Southwestern riparian ecosystems has been greatly reduced by these two plants that were so successful in their own reproduction (Dick-Peddie 1993). Native riparian species could not compete with these exotics; animals dependent on native species for food and shelter were impacted.

Clearly, American wildlands have been modified by intentional and unintentional human actions over thousands of years. Adjectives such as "pristine" and "untrammeled" seem idealistic for describing current wildland conditions, especially given the events of the past four centuries. Although some wildlands may still exhibit minimum human impact, the primeval, virginal conditions conjured up by the words "pristine" and "untrammeled" simply do not exist.

### Public Lands Were Created to Preserve America's Wildlands.

The myth that public lands were created to preserve America's wildlands ignores the historical, philosophical, and political contexts within which public lands were created. By 1832, America's infatuation with the machine had begun, and the impacts of the industrial age were evident on the landscape (Marx 1964). For 200 years, grazing, hunting, and timber harvesting gradually had re-shaped wilderness as "civilization" moved further west. But machines greatly accelerated this conversion of wildlands to farmlands and forest plantations as they facilitated the movement of raw resources to Eastern markets.

As wildlands disappeared, some American artists, philosophers, poets, and naturalists noted with regret the decrease in wild America. Although seldom removing themselves from civilization, they realized that much of what was considered uniquely American, its wild landscapes, was being lost. They sounded an environmental and philosophical alarm that continues to be echoed today. If Americans lose their wildlands, do they lose their identity as well as their resources? From Thoreau to Bierstadt and Emerson to Moran, artists' views of nature profoundly affected Americans' perceptions of wildlands. Artists substituted American landscapes for European classical heritage (Novak 1980). A young nation could not compete with the classical heritage of Europe, considered fashionable by wealthy Americans. But everyone in America, rich or poor, could be proud of the spectacular and wild landscapes that rivaled the grandeur of the Old World's heritage.

In 1872, Congress designated Yellowstone the first National Park; and by 1900, many more areas in the West were added. Parks were created for several reasons. First, with new technological developments in transportation, tourism for people of means was increasing. America's appetite for dramatic scenery was immense. It was now fashionable to see one's own country, and the railroads made it possible. Secondly, concerned citizens were fighting back against the land practices of "claim, grab, and raid" decried by Wallace Stegner (Athearn 1986).

A motivation similar to that which supported national parks also prompted a group of Americans to press for the establishment of forest reserves. In 1895, a system of forest reserves was established from the public domain. Although these lands were also set aside to prevent their imminent destruction, the long-range management goals of forests were different from those of parks. Parks were managed for scenic beauty and historical content; and forests were intended for the **sustained yield** of timber, water, and forage. By 1905, Congress, at the urging of President Theodore Roosevelt and Gifford Pinchot, created the Forest Service to scientifically manage national forests. In 1916, Congress established the National Park Service to manage the parks for the pleasure and education of the American public.

In 1913, an event that had been unfolding over many years reached its conclusion. In the arena of public land management, philosophical lines were drawn on the banks of the Hetch-Hetchy River in Yosemite National Park. Yosemite was the crown jewel of John Muir's many travels through American wildlands. An advocate of a national park system, Muir was incensed when the City of San Francisco applied to the federal government for water rights in the Hetch-Hetchy Valley. A dam would be needed to impound the water within the already established boundaries of Yosemite. Muir waged a running battle in the news media to keep all utilitarian projects out of Yosemite. But Gifford Pinchot, the new Chief of the Forest Service, supported the use of public water to meet the needs of a growing San Francisco. Muir lost the battle to preserve Hetch-Hetchy Valley, and his loss sealed his distrust of Pinchot's conservation ideology. If Pinchot was a conservationist (see Pinchot 1947), then Muir would be a preservationist (see Muir 1916). Muir and Pinchot, now mythic figures, symbolize the dichotomy of land use philosophies that had began over 100 years before (Nash 1967).

## MYTH IN FOREST MANAGEMENT

Just as forest ecosystems have ecological mechanisms for maintaining stability, human cultural systems have myths to correct imbalances. When commodity forestry is perceived as too destructive, environmental groups are motivated to action by 150 years of concern for the preservation of wildlands. When protection of plants and animals is perceived to lock out economically dependent local residents, some individuals and groups rally around 150 years of myths that the Western garden provides their living and freedom. When the availability of natural resources for industry and business is perceived as threatened, the myth of endless Western resources and the American right to convert raw material into domestic products are perceived as violated. And when the interests and actions of outside groups are perceived as threats to traditional cultures, community and spiritual leaders respond in terms of beliefs about the sacredness of the land and prior land use rights.

Mythologies are also prominent within the Forest Service. Consider, for example, the myths surrounding the ideal of "multiple use." Although the term itself came later, the concept of multiple use is derived from Pinchot's (1947) utilitarian social philosophy of forestry, "the greatest good for the greatest number in the long run." Historically, multiple use assumes that there existed an array of discrete forest interests and commodities which could be objectively weighed and allocated by a public agency in a wise and fair manner. This allocation is to be made at the local level and in such a way as to ensure a continuous flow of use and commodity into the future. National forests are thus seen as storehouses of resources to be managed and regulated for the public good. The agency, it is assumed, with its cadre of trained foresters knows best how to accomplish this.

Fire fighting is also steeped in mythology. According to the 1905 Forest Reserves Use Book, "Officers of the Forest Service, especially Forest Rangers, have no duty more important than protecting the Reserves from forest fire." Armed with this belief, the Forest Service and other public agencies launched an aggressive and highly effective fire suppression program that has dominated forestry for over 60 years. The myth that fire is the greatest enemy of the forest was reinforced over the years by the powerful symbol of Smokey Bear and the most effective public service campaign ever waged.

Both the mythologies of multiple use and Smokey Bear influence land managers' perceptions of the land as well as their perceptions of a role as stewards of the nation's forests. Under these myths, management tends to be functional, technology-based, and output-oriented. The interdependence of natural resources, adapting to change, and non-commodity uses may be recognized but are given less weight. Professionalism and agency autonomy are highly valued. Public dissatisfaction, when encountered, is attributed to the public's failure to understand and the need to better educate the public.

## THE SITUATION TODAY

How do mythologies play out today? The population in the Southwest has been increasing rapidly (see Figure 5.5). Unless states, counties, and towns place moratoriums on new growth and housing, populations will continue to grow. Many people and businesses moving into the Southwest bring entirely new mythology-based perceptions of wildlands with them. New mythologies are also at work within the Forest Service. As stated in the beginning of this chapter, mixing mythologies is at the core of American life. A diversity of mythologies may also be a source of insight and creativity in finding solutions to problems. Although it may not be an easy process, recognizing and respecting where others are coming from is a crucial step in the communication challenge now facing the Southwestern Region.

A review of Solomon's (1988) principles of semiotics may be helpful in looking into what people are really trying to say about their forests and themselves. Numerous people inside and outside the Forest Service continue to express a desire for national forests to be returned to "pre-settlement" conditions. Some individuals go so far as to want the Forest Service "to get out of the woods and let Nature heal herself." Still others see their independent way of life as loggers, ranchers, or farmers threatened by outsiders, both the government and the urban elite.

## CONCLUSION

There were vibrant native cultures using Southwestern forests long before Europeans arrived; and words like pristine and untrammeled are more idealistic than practical in the context of forest health. Nonetheless, public perceptions of the land and what it should provide cannot be discounted. Neither can an agency's own perceptions of management responsibility go unexamined. Forest health depends on the ability of people to communicate and collaborate to find not the "right answer" from a single perspective, but a range of useful solutions and experiments from which we all can learn.

Aldo Leopold (1949) observes that "the outstanding discovery of the 20th century is not radio, or television, but rather the complexity of the land organisms." Are human ideologies and relations any less complex? Sustaining forest ecosystems requires all of us to recognize that the land and the culture are one. Nature matters because we are nature. There is a human dimension to ecosystem management. This is a difficult task in an already complex and contentious social and political environment. A collaborative approach to internal and external communications seems essential, although it may seem at odds with the former Forest Service myth of autonomy. New visions that better serve the times can, perhaps, better serve public land stewardship. The basic challenge is whether we can align our internal mythologies and external relationships to successfully address the issue of forest health.

# CHAPTER 4: HISTORIC CONDITIONS

"Evaluating the status of existing ecosystems requires a standard or set of reference points that characterize sustainable ecosystems." Kaufmann et al. (1994)

Thousands of years of human occupation preceded the first written accounts, paintings, and photographs of Southwestern landscapes. We can only guess what the earliest occupants thought of their landscape. We know that prehistoric peoples altered vegetation by farming and burning; they shaped the land by terracing, field leveling, and stream channeling. Archeologists are just beginning to understand the extent of prehistoric occupation and do not know how prehistoric activities over the centuries have resonated across the landscape. For example, we know little of how burning or nutrient depletion by repeated cultivation affects vegetative patterns hundreds or thousands of years later. We need to view the whole notion of naturalness in the Southwest through the filter of prolonged and sometimes intensive human occupation. In the present and historical past, it is often very difficult to distinguish between natural and human-caused effects. For instance, what did cause widespread arroyo cutting in Southwestern deserts? Was it over-grazing, climate change, or a combination of both (Hastings and Turner 1965, Cooke and Reeves 1976)?

The period used to characterize historic conditions in this chapter is that prior to the Mexican-American War of 1848. This date is selected as a central point between the 1845 annexation of Texas and the 1853 Gadsden Purchase. These events mark the political transition from Hispanic to American sovereignty in the Southwest and its opening to new and increasing waves of settlement. The view through time's fuzzy lens becomes a little clearer as we approach the present. After the Civil War, members of various expeditions and surveys began to photograph the Southwestern landscape. General agreement between 18th century photographs and 16th century written accounts indicate that the landscape had maintained some degree of consistency over those centuries. If this agreement were valid, then photographs taken in the 1880s (and possibly as late as the 1920s for the Colorado Plateau) could represent the general forest character during at least the last few centuries. The consistency of forest attributes in early Colorado Plateau photographs supports this hypothesis (Hastings and Turner 1965, USDA Forest Service photographs 1901-1968[3]). There is, however, one note of caution in use of old photos to characterize the past. Artistic bias and commercial interests may have favored certain landscapes and views over more common ones; historic photographs may not be representative of earlier landscapes.

## CLIMATE

A description of past forest conditions in the Southwest begins with a review of climate history. Although regional climates persist for centuries, they do change and vegetation responds on a similar scale (Delcourt et al. 1983). The forest ecosystems we see today or in hundred-year-old photographs are the products of species evolution and migration over aeons of time on a constantly shifting landscape driven by changes in climate. From a broader perspective and context, the climate during the few centuries before 1848 was unique.

Climates change at a variety of scales (Delcourt et al. 1983). Long-term, persistent trends in temperature and humidity determine the extent and location of the various life zones, the elevation at which one biotic community replaces another.

*[3] On file at the Cline Library, Northern Arizona University, Flagstaff, AZ.*

Shifts from one climatic regime to a new pattern can be abrupt. Evidence from Greenland ice cores suggests the 1300-year cold spell of the Younger Dyras (11,200–10,000 **B.P.**) ended over a period of only a few years (Betancourt et al. 1993). Short-term fluctuations in the order of years to decades determine drought cycles, fire frequencies, and pulses of tree reproduction. The Southwest is strongly influenced by oscillations in the Pacific ocean-atmosphere system; years of El Nino bring increased annual precipitation (but less rain in summer) and years of La Nina bring the opposite (Betancourt et al. 1993).

Data from geology, **paleobotany**, and **dendrochronology** studies at Potato Lake and Chaco Canyon permit a reconstruction of the climate history of the Southwest. Potato Lake (Anderson 1993) is a high elevation site (7,500 feet) in the Arizona–New Mexico Mountains Province. In the mid-Wisconsin Period (35,000–21,000 B.P.), the area was dominated by mixed conifer species; in the late-Wisconsin (21,000–10,400 B.P.) by spruce alone; and for the past 10,400 years by ponderosa pine. The Chaco Canyon and San Juan Basin (Betancourt et al. 1993) is a lower elevation region in the Colorado Plateau Province. Before 8,000 B.P. a relatively cold and moderately wet climate prevailed; the canyons contained a mixed conifer forest and the mesa tops a cold desert steppe. During the Altithermal Period (8,000–4,000 B.P.) pinyon and juniper migrated into the area and replaced the mixed conifer forests; warm desert grasses replaced the sagebrush of the cold desert steppe. The cause of these vegetation changes is thought to have been the arrival under generally warmer conditions of a monsoonal circulation with warm wet summers. A cooler and dryer Neoglacial Period lasted from 5,000 to 2,000 B.P. The climate of the past 2,000 years is considered modern (Cartledge and Propper 1993), but it includes several notable, global events—the Medieval Warm Period from 1000 to 1350 A.D. and the Little Ice Age from 1450 to 1850 A.D. (Nielson 1986). In the Southwest, higher average summer temperature and precipitation persisted from 950–1130 A.D. and prolonged summer droughts occurred from 1130–1180 A.D. (Cartledge and Propper 1993). Cycles are not only in the past. In 1996, Arizona endured one of the worst droughts since 1904; tree damage was detected on 57,000 acres of Federal forests (USDA Forest Service 1996a).

## FIRE

Both lightning and human-caused fires, once started, could burn until extinguished by rain, or until they ran out of **fuel** (typically when they reached an area that had recently burned). Fires could burn for months and cover thousands of acres (Swetnam 1990, Swetnam and Baisan 1996). As a result, most forest stands (except spruce–fir) burned every 2 to 30 years as low-intensity, area-wide fires. Fire reconstructions in the Pinaleno Mountains of southern Arizona demonstrate that pre-settlement mixed-conifer forests could have burned as frequently as the ponderosa pine forests (Grissino-Mayer et al. 1995). With greater moisture levels but heavier fuel loads, spruce–fir forests burned much less frequently but at high, stand-replacing, intensity (Grissino-Mayer et al. 1995, Veblen et al. 1994). Research by Cable (1975), Dieterich (1980, 1985), Grissino-Mayer et al. (1995), Leopold (1924), and Weaver (1951) establish the range of pre-settlement fire frequencies for Southwestern forest communities (Table 4.1). The role of native peoples in modifying fire regimes of the interior West is examined by Arno 1985, Gruell 1985, Barrett 1988, Savage and Swetnam 1990, and Veblen and Lorenz 1991. Native cultures used fire for a variety of purposes (Pyne 1982, Phillips 1985). In addition to incidental burning, there is ample evidence that fires were intentionally set for increasing desired plant species, improving wildlife habitat, driving game animals, and clearing transportation routes. Pinchot (1947) describes a scene where:

> "We looked down and across the plain. And as we looked there rose a line of smokes. An Apache was getting ready to hunt deer. And he was setting the woods on fire because a hunter has a better chance under cover of smoke."

**Table 4.1 Frequency of area-wide fires in Southwestern forests prior to European settlement.**

| Biotic Community | Fire frequency (years) |
|---|---|
| Pinion-juniper | 10-30 |
| Ponderosa Pine | 2-10 |
| Mixed conifer | 5-25 |
| Spruce-fir | 150+ |

Based on data from Cable (1975), Dieterich (1980, 1985), Grissino-Mayer et al. (1995), Leopold (1924), and Weaver (1951).

In many areas of the West, American Indians altered succession using fire (Gruell 1985). In the Southwest, however, the historic fire regime does not depend on native burning (Swetnam and Baisan 1996). Lightning is common in many parts of the Southwest during periods of high **fire hazard**; these rates and patterns would have prevailed in earlier times as well (Schroeder and Buck 1970). Lightning ignition alone is sufficient to produce the fire frequencies revealed in various fire-scar chronologies. The effect of native peoples on fire in the Southwest would probably have been very site- and time-specific (Swetnam and Baisan 1994).

The ecological role of fire in Southwestern forests has always been significant. Where fire was more frequent, forest communities even developed a dependency on fire as a mechanism for ecosystem regulation (Wright and Heinselman 1973). Where fire was infrequent such as in the spruce–fir forest, fire was still a major abiotic factor, but its effects and integration into the ecosystem had a very different character. Like all disturbances (such as grazing, fuelwood collection, mortality from insects and diseases) fire affected species composition, the amount, distribution, and proportion of living and dead biomass, and various ecosystem functions (e.g., nutrient cycling).

## DEMOGRAPHICS AND LAND USE

For more than 12,000 years, humans have been an integral component of Southwestern forest ecosystems; but the archaeological record is fragmentary and poorly sampled. Precise estimates of regional populations in prehistoric times do not exist, although information on general population trends are evident (Dean et al. 1994). For at least 10,000 years, a sparse population dependent on wild plants and animals occupied the Southwest. Beginning around 300 A.D., the population in certain areas of the Southwest increased with a shift to greater reliance on domesticated plants and development of more permanent settlements. By 600 A.D., the increase was regionwide. With the growth of larger, more complex communities throughout the region, the population peaked at perhaps 130,000–150,000 in the 11th to 13th centuries (Dean et al. 1994). Beginning about 1300 A.D., many areas of the Southwest were abandoned; and the regional population probably declined, although to what degree is uncertain. Anasazi populations appear to have re-aggregated into large pueblos along the Rio Grande and in the Zuni and Hopi areas. The Hohokam and Salado populations, however, appear to have dispersed. Such shifts in population and settlement had probably been repeated throughout prehistory in various ways and at various scales as societies responded to changes in climate, resource availability, and political, economic, and social pressures (Cordell 1984, Gumerman 1988, Tainter and Tainter 1996). These fluctuations in late prehistoric times, however, were dwarfed by the major reduction of native populations that began with the arrival of Spanish colonists.

Impacts of prehistoric populations are thought to have been minimal or highly localized until the 11th and 12th centuries. At that time, farming, fuelwood cutting, and game hunting greatly increased around new, dense settlements. There is evidence in the Phoenix Basin that main irrigation canals during the Classic Hohokam Period (1200-1400 A.D.), totalled more than 500 kilometers (Spoerl and Ravesloot 1994) and that irrigated fields covered 150 square kilometers (Nicholas and Neitzel 1984). In other areas where dry farming and floodwater farming were practiced, similar intensive use and alteration of the landscape is apparent (Fish and Fish 1992, Lang 1995). Impacts on the environment in late prehistoric times, along with drought, crop failure, and population stress, probably contributed to local and regional cycles of settlement abandonment, and relocation.

In the Southwest, as elsewhere in the New World, the arrival of Europeans had a catastrophic impact on native populations. Epidemics, starvation, hostilities, subjugation, and relocation devastated native peoples. Pueblo populations in New Mexico, for example, were reduced from perhaps as many as 60,000 in the 1500s to fewer than 7,000 by 1706 (Schroeder 1979). Some groups disappeared entirely, including the Piro of central New Mexico and the Sobaipuri of southern Arizona. The degree to which the effects of disease may have preceded the actual arrival of Spanish colonists is unknown.

The Spanish population during the Colonial Period remained relatively small, due to their dependence on irrigation agriculture and hostile relations with the Apaches, Navajos, Utes and Comanches. The Spanish population in New Mexico is estimated to have been only 2,500–3,000 in 1680, and was perhaps no more than 20,000–25,000 by the late 18th century (Simmons 1979). Because the population was small except along certain permanent streams, regional impacts during the Colonial Period were not much different from those of late prehistoric times. The notable changes were the shift to more intensive irrigation and the introduction of new crops and animals. The population grew during the later Mexican Period; sheep grazing increased significantly; and mining expanded in certain areas.

## TIMBER AND FUELWOOD RESOURCES

Prehistoric populations used wood for fuel, tools, and construction. In late prehistoric times, pinyon and juniper were locally depleted in some areas (Bahre 1991, Betancourt et al. 1993, Cartledge and Propper 1993, Kohler 1992, Stiger 1979). As many as 200,000 ponderosa, spruce, and fir beams were used for construction of the 10 major puebloes and kivas at Chaco Canyon (Betancourt et al. 1986). At least near large settlements, impacts on adjacent upland forests may have been significant.

In historic times prior to 1848, only small-scale utilization of timber resources was possible because of technological and transportation limitations. Native American and Hispanic populations used the forests for lumber in domestic construction and for firewood. Woodland and riparian forests were affected, especially near areas of population growth. The riparian bosque of the Middle Rio Grande Valley, for instance, had been virtually eliminated by Puebloan and Hispanic farmers before 1848 (Abert 1848a, Wozniak 1987). But impacts on upland forests were probably negligible before the introduction of commercial logging, mining, and railroads in the late 19th century.

## FOREST INSECTS AND PATHOGENS

For millennia, trees of Southwestern forests have been host to numerous species of herbivorous insects, pathogenic or saprophytic fungi, and parasitic plants. These species co-evolved with their hosts as members of dynamic, interacting communities. Through their ability to cause widespread tree mortality, defoliation, decay, or deformity, some of these species achieved significant ecological importance as disturbance agents. Along with fire, these agents are among the more important regulators of forest density, composition, and structure. Forest conditions in turn affect the distribution and reproduction of forest insects and pathogens. Directly and indirectly, these species interact with other members of the ecological community influencing various ecosystem processes, providing food and creating habitat for other organisms, affecting nutrient recycling, and influencing fire behavior.

The species of primary interest in the Southwest include bark beetles, several species of defoliating insects, **dwarf mistletoes**, and root decay fungi. Bark beetles and defoliators are usually present in low populations, but they will periodically increase to outbreak levels. Although populations of dwarf mistletoe and root decay fungi fluctuate, their rates of change are much slower. These species, however, are very persistent and affect forests annually rather than periodically.

Descriptions of previous outbreak patterns for insects or distribution and abundance of pathogens are developed from inference or observation. Details for prior disturbance regimes of insects and pathogens may be inferred if one assumes their fundamental biology (e.g., host preferences) has not changed and if one has data on past climate and vegetation. Observations on the distribution and severity of outbreaks prior to the past few decades are limited to early written reports and photographs and to later reports of forests little affected by harvest, grazing, and fire. Some characteristics of prehistoric outbreaks can also be determined by various reconstruction techniques (e.g., paleobotany and dendrochronology). The host and environmental requirements of native insects, fungi, and parasitic plants has probably changed little over the recent centuries, so it is reasonable to expect that where and when conditions were suitable, these disturbance agents would have been active. Systematic surveys and reporting of insect outbreaks and disease occurrence only began in recent decades (unpublished reports[4] and USDA Forest Service 1972). As mentioned previously in reference to old photographs, the early reports must be interpreted with caution, not because they are inaccurate, but early entomologists may have viewed forests with different objectives and values ("conceptual filters.")

### Bark Beetles

Numerous species of bark beetles attack and kill trees (Furniss and Carolin 1977). Bark beetles generally have a narrow host preference within several related

*[4] Forest insect conditions, R-3, 1918-1952; photocopied letters and annual reports on file; Flagstaff, AZ: U.S. Department of Agriculture, Forest Service, Arizona Zone Entomology and Pathology.*

genera or a single genus; within portions of a beetle's range only a single host species may be available (Wood 1982). In the Southwest, the most important bark beetles on ponderosa pine are the roundheaded pine beetle (*D. adjunctus*), western pine beetle (*D. brevicomis*), mountain pine beetle (*Dendroctonus ponderosae*), pine engraver (*Ips pini*), and the Arizona fivespined ips (*I. lecontei*). The Douglas-fir beetle (*D. pseudotsugae*) on Douglas-fir, the fir engraver (*Scolytus ventralis*) on white fir, the spruce beetle (*Dendroctonus rufipennis*) on Engelmann spruce, and the western balsam bark beetle (*Dryocoetes confusus*) on subalpine fir are also important bark beetles. Successful attack usually leads to rapid tree death, but if attack is restricted to only a portion of the bole, top-killing or strip-killing may occur (Stark 1982). At low population levels, bark beetles are usually restricted to scattered individual trees that have been weakened by disease, old age, or competition and to fresh logs and slash caused by windthrow or snow breakage. In outbreaks, small groups of killed trees eventually merge into large stands of dead trees.

Bark beetles affect and are affected by the forest community in numerous ways. By selectively killing trees of certain sizes and species, bark beetles change tree density, species composition, and size structure of the forest (Schmid and Frye 1977). Extensive and severe outbreaks can increase fire hazard (Martin and Mitchell 1980). The beetles, their associates, and successors provide food for insectivorous birds (especially woodpeckers); the resulting snags provide habitat for cavity-dependent species. Changes in forest conditions brought on by beetle-caused mortality modify the environment for numerous other species. Principal factors that influence bark beetle outbreaks are susceptible host population, weather, and natural enemies. Factors that lower tree resistance, such as poor site, overcrowding, drought, injury, and disease, favor outbreaks. Depletion of suitable hosts, extreme cold temperature, and natural enemies (insect predators and parasites, fungal diseases, and birds) contribute to population declines.

The earliest published reports of bark beetles in the Southwest date from the early 1900s; information prior to 1848 is scarce. In the early 1900s, entomologists from the USDA Bureau of Entomology conducted the first detailed investigations on various species of *Dendroctonus* beetles in Arizona and New Mexico (Hopkins 1909). From their reports, it appears that large outbreaks occurred in certain forest types and regions but were rare or insignificant in others.

Hopkins (1909) reports an outbreak of spruce beetle on the slopes of Sierra Blanca Peak, south central New Mexico. Baker and Veblen (1990) use historic photos and dendrochronology data to reconstruct disturbance regimes. They determined that the spruce beetle has been a major disturbance agent, comparable to fire, from central New Mexico to Colorado since the 19th century. Because fire suppression and logging have had less effect on spruce–fir forests than other communities, disturbance regimes observed today are probably a good reflection of what they had been in earlier historic times.

Hopkins (1909) notes that levels of pine beetle activity were less in the Southwest than he had observed in other Western regions. Woolsey (1911) concurs that mortality from the mountain pine beetle was less continuous and extensive in Arizona and New Mexico than elsewhere. These are curious reports considering that at the time (early 1900s) the Southwest was experiencing a severe drought which ought to have stressed trees and made them susceptible to attack. On the other hand, even today, forests of large, widely-spaced pines and few understory trees rarely support outbreaks.

The exception to observations of limited pine beetle activity in the Southwest is found on the Kaibab Plateau of northern Arizona. Blackman (1931) provides evidence for early outbreaks of mountain pine beetle in ponderosa pine. This section of the Colorado Plateau Province seems to have had a long history of large outbreaks by the mountain pine beetle. The largest outbreak occurred between 1917 and 1926 and killed about 12 percent of the ponderosa pine growing stock. Five earlier outbreaks dating back to 1837 were identified, but neither their extent nor magnitude are well documented. Why pine bark beetles were so active here and not so elsewhere is an intriguing question.

## Defoliating Insects

### *Western spruce budworm*

The western spruce budworm (*Choristoneura occidentalis*) feeds on foliage of true firs, Douglas-fir, and spruce throughout the western United States. In the Southwest, its principal hosts are white fir and Douglas-fir (Linnane 1986). Larvae feed primarily in buds and on foliage of the current year. Complete defoliation occurs when outbreaks persist for several years. Sustained heavy defoliation results in decreased growth, tree deformity, top-killing, and death. Stand-level effects include changes in stand structure and composition. Tree mortality is generally more prevalent in the smaller, suppressed, understory trees, so outbreaks result in fewer understory trees and increases in the average diameter. Species composition shifts to nonhost or less susceptible species. In mixed-species stands where true fir, spruce, or Douglas-fir are climax species, budworm outbreaks increase the relative abundance of early **seral** species such as ponderosa pine or southwestern white pine (Wulf and Cates 1987). In stands with only late seral hosts, outbreaks are a natural thinning from below, removing understory trees and stimulating growth of overstory trees.

In addition to the direct effects on forest trees, western spruce budworm affects other members of the forest community. Twenty-six species of birds are known to feed on budworm. Some of these consume large numbers of budworm, and their populations may increase in outbreak areas (Garton 1987). Outbreaks of Douglas-fir beetle sometimes follow after those of the western spruce budworm.

Swetnam and Lynch (1989, 1993) use dendrochronology to reconstruct the long-term, regional outbreak history of western spruce budworm in northern New Mexico (Southern Rocky Mountain Province). Nine regional outbreaks are identified from 1690 to 1989, with a periodicity of 20 to 33 years, and duration within stands of approximately 11 years. Most stands, including one over 700 years old, had endured multiple infestations, suggesting that Douglas-fir and budworm may coexist in the same stands over long periods. Budworm activity tends to coincide with increased spring precipitation. Budworm history and behavior in other Southwestern provinces is expected to be different, but research in these areas is not complete.

### *Western tent caterpillar*

The western tent caterpillar (*Malacosoma californicum*) is a native insect that feeds on the foliage of aspen and is an important defoliator in the Southwest. Outbreaks occur sporadically and can result in extensive defoliation, growth loss, top kill, or even mortality. Outbreaks typically persist in an area for several years and flare up in one stand and then another. In a few areas, however, there have been repeated sustained outbreaks (Jones et al. 1985). Outbreaks eventually subside from a variety of biotic factors, particularly natural enemies such as viruses, insect parasites and predators, and birds. The most important control is a nucleopolyhedrosis virus which affects larvae (Furniss and Carolin 1977). The authors are unaware of any reports of the incidence or activity of this insect prior to 1848, but if aspen were more extensive then, outbreaks could also have been more common.

## Root Decay Fungi

Root diseases are common throughout the Southwest in many stands of mixed conifer and spruce–fir forests and some pinyon or ponderosa pine stands (Wood 1983). The most important root diseases are caused by the decay fungi *Heterobasidion annosum* (affecting ponderosa pine and white fir), *Phaeolus schweinitzii* (primarily affecting Douglas-fir), *Inonotus tomentosus* (affecting spruce) and *Armillaria* spp. (affecting nearly all species). These fungi injure trees by decaying and killing roots. Spread occurs by wind-disseminated spores which infect through basal wounds, through root contacts between healthy and infected trees, or through **rhizomorphs** (only for *Armillaria*). These fungi can persist for decades in the roots of stumps and snags and infect susceptible regeneration through root contact (Shaw and Kile 1991, Otrosina and Cobb 1989, Tkacz and Baker 1991). Root disease infection reduces growth and survival and increases risk of mortality by bark beetles or windthrow.

Although some **seedling** and **sapling** trees are killed by root disease fungi, their principal ecological effect is through the death of canopy trees, either as single individuals or groups in slowly expanding patches. Disease centers persist for hundreds of years and appear as openings with progressively more recently-killed trees at the edge. Some regeneration may establish within a disease center, but these trees only escape mortality for a few years. Because there are species differences in susceptibility and tolerance, affected stands may exhibit species conversion (even from trees to brush). Increases in canopy diversity greatly impact habitat quality; whether the change benefits or harms a species depends on its individual requirements.

Although the authors know of no early reports describing the distribution and extent of root disease centers in the Southwest, their longevity and ubiquity suggest that root disease fungi have always been important disturbance agents, especially on more mesic sites (Wood 1983).

## Dwarf Mistletoes

The dwarf mistletoes (*Arceuthobium*) are highly specialized dicotyledonous parasites of conifers (Hawksworth and Wiens 1996). Most conifers species in the Southwest are parasitized by one or another species of *Arceuthobium*. Because of their abundance and severe damage to infected trees, the most important dwarf mistletoes are the southwestern dwarf mistletoe (*A. vaginatum* subsp. *cryptopodum*) on ponderosa pine and the Douglas-fir dwarf mistletoe (*A. douglasii*) on Douglas-fir. Mistletoes acquire their water, mineral nutrients, and carbohydrates from a living host (Tocher et al. 1984), thereby reducing and re-allocating host growth. Many species of mistletoe, including the southwestern dwarf mistletoe and the Douglas-fir mistletoe, induce proliferation of dormant buds, localized swellings, and retention of infected branches; leading to the formation of distinctive witches brooms. Although intensification within an infected tree is slow (Geils and Mathiasen 1990), survival is greatly reduced (Hawksworth and Geils 1990).

Dwarf mistletoes affect wildlife habitat both directly and indirectly (Hawksworth and Wiens 1996). Mistletoes provide food, foraging sites, and nesting for numerous species; structural changes from brooms, snags, and openings (Parmeter 1978, Tinnin 1984) benefit the abundance and richness of nesting passerine birds (Bennetts et al. 1996).

The spread and intensification of dwarf mistletoe are affected by numerous host, stand, and environmental factors. Site quality, host vigor and age, stand density, composition, and structure are several of the more important factors (Parmeter 1978) in determining the rate of mistletoe increase. In the historic period, fire had been a significant factor in determining mistletoe distribution and persistence (Alexander and Hawksworth 1976). Although severe crown fires can sanitize an infested stand, partial burns leave scattered infected seed trees and insure early re-infection of the regeneration. Increased fine fuels and brooms on infected trees provide a fuel ladder to carry ground fire into the crown, thereby leading to complete, stand-replacing fire. Even in low-intensity fires, mistletoe reduces the survival of infected trees (Harrington and Hawksworth 1990).

Although there is little information on the previous abundance of dwarf mistletoes, they were probably already well distributed throughout the forests of the Southwest by historic times. Paleobotanical evidence supports the hypothesis that these parasites have been in western North America since the Miocene Epoch (Hawksworth and Wiens 1996). Because spread is relatively slow and long-distance dispersal rare, the extent of mistletoe distribution in the historic period is probably well reflected by the current distribution. Based on present understanding of mistletoe ecology (Parameter 1978) and evidence of previous forest conditions and fire frequency, one can infer that mistletoe abundance may have been lower in the historic period.

# HISTORIC CONDITION BY FOREST COMMUNITY

## Woodlands

Prior to 1848, many of the areas now occupied by dense woodlands were predominantly open, diverse communities of trees, shrubs, and perennial grasses and forbs. However, there were dense woodlands reported early in the 19th century. Abert (1848a, 1848b), for example, describes a trip between Santa Fe and Taos which began in a pinyon woodland with no grass. From the plateau east of the Rio Grande, he entered the canyon at Embudo where he reports little pasturage and that residents raised goats because there was insufficient vegetation for cattle. Leopold (1951) compares 20 pairs of photographs in stands of pinyon–juniper from nine different geographic localities. The earliest of the pairs were taken between 1895 and 1903; the latter were taken between 1937 and 1946. The number of trees increased in 7 pair, remained unchanged in 10 pair, and decreased in 3 pair.

Woodlands consist of dispersed groups of pinyon, juniper, or oak; the areas between tree patches may be mostly bare or covered by sparse litter, shrubs, or grasses. The pattern of tree patches is strongly influenced by ecosystem conditions and processes both below ground and above. Variations in soil depth, nutrients, and microbes interact with seasonal annual drought, plant competition, fire, grazing, and insect–pathogen attack (Gehring and Whitham 1995, Klopatek et al. 1990, Leopold 1924). In the historic period, native use of woodlands for timber and fuelwood had a significant effect (Betancourt et al. 1986).

## Ponderosa Pine

Numerous documents (e.g., Biswell et al. 1973, Brown and Davis 1973, Cooper 1960) refer to historic ponderosa pine stands as open, parklike, and with a vigorous and abundant herbaceous understory. Captain Sitgreaves in 1854 describes an apparently typical ponderosa pine scene where "the ground was covered with fresh grass, and well timbered with tall pines." Photographic and written records of historic forest conditions and archaeological reconstructions suggest that the characteristic vegetation was a grass matrix with individuals, clumps, and stringers of large and variously-sized trees of almost exclusively ponderosa pine.

An area now within the Coconino National Forest is described in a U.S. Geological Survey (1904) report as:

> "A yellow-pine forest, as nearly pure as the one in this region, nearly always has an open growth, but not necessarily as lightly and insufficiently stocked as in the case in this forest reserve. The open character of the yellow-pine forest is due partly to the fact that the yellow pine flourishes best when a considerable distance separates the different trees or groups of trees. It is very evident that the yellow-pine stands, even where entirely untouched by the ax, do not carry an average crop of more than 40 per cent of the timber they are capable of producing ... The yellow-pine forest in the reserve is, broadly speaking, a forest long since past its prime and now in a state of decadence ... Apparently there has been an almost complete cessation of reproduction over very large areas during the past twenty or twenty-five years (due mostly to sheep use), and there is no evidence that previous to that time, it was at any period, very exuberant."

Although the popular early descriptions of the ponderosa pine forest call attention to the parklike stands, there are also descriptions which refer to dense cover (Woolsey 1911). An accurate picture of the pre-settlement ponderosa pine forest would most likely describe a mosaic not only with an open, grass savanna and clumps of large, yellow-bark ponderosa pine, but also with a few dense patches and stringers of small, blackjack pines (young ponderosa pine). Ponderosa pine naturally regenerates rarely, but then reproduces with an over abundance of seedlings and a high rate of juvenile mortality (Pearson 1931). The large yellow-bark ponderosa pine of late 1800s were probably survivors that emerged from dense patches established during rare episodes of successful reproduction (climatically unusual periods of high moisture and infrequent fires). These patches would have provided needed cover for not only various wildlife species (e.g., wild turkey, *Meleagris gallopava*) but also the conditions for mistletoes and bark beetles to persist and even locally flourish.

The typical climate over the several centuries prior to 1848 and the development of a fire-dependent vegetation reinforced a fire regime of frequent, low-intensity burns (Covington and Moore 1994b). On an area-wide basis, surface fires burned within the montane zone where ponderosa pine is either climax or seral every 4.8 to 11.9 years (Weaver 1951). Fires of this frequency were sufficient to normally prevent reproduction by ponderosa pine or other species of the mixed conifer community. These fires, however, encouraged development of grassy understories and retention of large, open-grown ponderosa pine.

The typical climate of the ponderosa pine zone includes an adequate, annual amount of moisture for good vegetative growth and conditions favorable for frequent early summer fires (Harrington and Sackett 1992). Winters are relatively mild (average slightly above 30 F) and precipitation as snow saturates the soil (Schubert 1974). Rainfall minimums occur in May and June (some areas receive less than 0.5 inch). The spring dry season is accompanied by increasing air temperatures, low humidity, and persistent winds. The drought is broken in early to mid-July with development of almost daily thunder and lightning storms; July and August are the wettest, warmest months. A second dry season occurs in the fall. This climatic pattern is particularly conducive for development of a pine-grass savanna maintained by frequent surface fires.

Open stands of ponderosa pine under a frequent fire regime are capable of supporting a productive understory and associated grazing populations. Clary (1975) reports that open pine stands can produce at least 200 to 300 pounds per acre of herbaceous material; Cooper (1960) estimates that production could exceed 1,600 pounds per acres in frequently burned stands. These high levels are the result of surface fires which increase nutrient cycling and reduce competition from woody reproduction. Needle cast and litter from the previous year's grassy and herbaceous growth form a highly flammable fuel that is easily dried out in the spring and ignited in the early dry lightning storms (Pyne 1982). Because fires are frequent, large amounts of woody fuel do not accumulate and crown fires are uncommon. These frequent, surface fires kill small trees, but the still dormant grasses and forbs survive, and large trees escape damage because of their high crowns and thick barks (Biswell et al. 1973). These forests (Biswell 1972, Cooper 1960, Hall 1976, Weaver 1947) support elk and deer as the dominant grazers; disease, predators, and other population regulation mechanisms keep vegetation and herbivores in balance.

The more dense and younger stand structures of the historic ponderosa pine forest were the result of special circumstances in the interaction of climate and site. Even though ponderosa pine reproduction was rare, there were occasional wet cycles as long as 15 to 20 years without fires when ponderosa pine could regenerate (Swetnam and Dieterich 1985). The regeneration cycle required seed production, establishment, and survival to an age at which the young tree could successfully compete and endure surface fires. In the historic period, most large trees were killed by lightning (and associated fire), dwarf mistletoe, bark beetles, windthrow, or senescence. When single or small groups of trees died and fell, they were inevitable consumed by surface fires. This more severe, but localized, fire treatment produced mineral soil seedbeds and reduced grass competition, thereby creating a favorable microsite for establishment (Cooper 1960). Within these severely burned microsites with little competition and fuel, seedlings could survive, grow, and develop their competitive ability and resistance to fire. Replication of this pattern within the pine-savanna resulted in an uneven-aged forest composed of small, relatively even-aged groups (Cooper 1960).

## Mixed Conifer

Early descriptions of the mixed conifer forest indicate they included a variety of conditions depending on the time since and the severity of the most recent burn. Lang and Stewart[5] describe the mixed conifer forest on the North Kaibab Plateau (Colorado Plateau Province) in 1909. Although the date is later than 1848, this particular region had been only sparsely settled by that time. They describe most mature Douglas-fir (as well as white fir and blue spruce) as "deteriorating"; they probably mean these trees were decayed, had poor crown form, broken tops, and hollow bases typical of repeatedly fire-damaged trees. Lang and Stewart also note that Douglas-fir regeneration was "healthy and vigorous"; and often dense stands of pole-sized trees covered large areas, especially on more mesic sites and under aspen. The older stands had probably survived numerous, light fires. On xeric or warm–dry sites (white fir and Douglas-fir habitat types, and those with seral ponderosa pine) mixed conifer stands burned about every 5 to 12 years (Weaver 1951). On mesic or cool–moist sites (spruce–fir habitat types) in the White Mountains of Arizona, area-wide fires occurred with an average return interval of 22 years (Dieterich 1983). As the interval between fires increases more fuel accumulates and the likelihood of a stand-destroying crown fire increases. The younger stands described by Lang and Stewart had probably established following a severe fire. Moir and Ludwig (1979) declare that most mixed conifer stands are established in this manner. These severe fires may either directly produced a stand of conifers or a stand which first goes through an aspen stage (Pearson 1931, Pearson and Marsh 1935).

*[5] Unpublished report titled Reconnaissance of the Kaibab National Forest, unpublished survey report circa 1910 on file Williams, AZ: U.S. Department of Agriculture, Forest Service, Kaibab National Forest.*

## Spruce–Fir

Because many spruce–fir forests in the Southwest had been little affected by logging, grazing, or fire suppression until very recently, the historic conditions and disturbance regimes of this community can be reconstructed with good precision and reliability.

The major disturbances in the spruce–fir forests of the Southwest are fire and bark beetles (Baker and Veblen 1990, Schmid and Frye 1977). Although these agents are capable of reshaping whole landscapes by conflagration or outbreak, these events are relatively infrequent (100+ years between major disturbances, see Veblen et al. 1994). In these wet forests, ignitions are rare, but heavy fuel accumulations and steep slopes result in high-intensity, crown fires lethal to the subalpine vegetation (Grissino-Mayer et al. 1995). The different species of bark beetles are selective for either spruce (usually developing in blowdown) or subalpine fir (often associated with root disease). Snags created by these events can remain for decades (Schmid and Hinds 1974). The species and patterns of regeneration are highly variable and depend in the long term on climate (Anderson 1993) and in the short term by site conditions and immediate disturbance history (Rebertus et al. 1992, Patten and Stromberg 1995). On wetter sites protected from intense radiation, Engelmann spruce and subalpine fir usually take and hold early dominance of the site (Fowells 1965). On drier sites, aspen, Douglas-fir, and southwestern white pine may become established initially and spruce and fir later emerge as dominants (Lebarron and Jemison 1953).

### Aspen

Although aspen is usually successional to conifers, the aspen community has always been an important component of Southwestern forests. Precise estimates of forest area occupied by aspen before the mid-19th century are not available, but since that time acreages have declined with cessation in burning (Jones and DeByle 1985). The successional dynamics and ecological role of aspen stands are well known and little changed since the historic period.

Aspen stands are usually very quite wet and do not readily burn; aspen stems, however, have only a thin bark and are easily killed by a light fire (Baker 1925). After a fire, aspen re-sprout or sucker from shallow lateral roots (Gruell and Loope 1974). Although aspen is a climax species on some sites, it is usually seral to conifers (Mueggler 1976). This replacement is gradual and can take from 100 to 200 or more years (Bartos et al 1983). If an aspen stand is within a mixed conifer forest, conifers can become established within a single decade (Jones 1974). Because aspen stands are so different from conifer stands, they are very important for landscape diversity and wildlife habitat. Although aspen stems are short lived and snags do not stand long, the wood is soft, often decayed, and therefore useful to cavity-dependent species. Young sprouts are heavily browsed by elk and deer.

### Riparian Wetlands

The Colorado and Rio Grande River systems in Arizona and New Mexico extend from headwater tributaries in high, forested mountains to the lowlands of the subtropical Sonoran and Chihuahuan Deserts (Minckley and Rinne 1985). Continuous corridors of riparian vegetation once covered hundreds of miles along desert rivers in the Southwest. Besides forested riparian communities, there were riparian shrublands, marshlands, and grasslands. These plant communities were found at elevations from high wet meadows and cienegas, to tree-banked streams, to slack water sloughs and marshes—the alpine, montane, and floodplains-plains riparian ecosystems (Dick-Peddie 1993).

Riparian ecosystems served as permanent habitat and seasonal migration routes for many species of birds and mammals. Rivers and spring-fed cienegas supported specialized, endemic fish species. Beaver (*Castor canadensis*) required water and created ponds to retain it during periods of low flow. Open water for drinking was essential for some animals such as doves and bats (e.g., the spotted bat, *Euderma maculatum*). Other species like the southwestern willow flycatcher (*Empidonax trailii extimus*) and the ferruginous pygmy owl (*Glaucidium brasillianum*) depended on the special plant and animal communities of a riparian wetland.

Alpine plant associations in the Southwest are dominated by graminoids—especially, sedges or *Carex*, other aquatic plants in the genera *Cyperus*, *Juncus*, and *Scirpus*, and grasses of the genera *Deschampsia*, *Agrostis*, and *Glyceria*. By trapping **sediments** moving over the channel bottom these native aquatic plants are important for protecting the long-term stability of alpine meadows or cienegas.

A large proportion of the Southwest's "live" streams pass through the upland montane forests of the mixed conifer and ponderosa pine communities. The riparian zones themselves are usually narrow, often following relatively steep stream channels in restricted valleys. The watercourses are flanked by hardwood and coniferous riparian plant communities. Narrowleaf cottonwood, box-elder (*Acer negundo*), bigtooth maple (*Acer grandidentatum*), Scouler willow (*Salix scouleriana*), and arroyo willows (*Salix lasiolepis*) are typical hardwoods. White fir and blue spruce are the common conifers in and adjacent to riparian ecosystems (Szaro 1989, Minckley and Brown 1994). These streams usually flood from snowmelt in the spring; and many riparian species depend on overbank flooding for seed transport and burial in fresh, fertile alluvial sediments. Historically, seed shedding and flooding usually coincided.

The vegetation and stream channels between the montane and subtropical floodplains are markedly diverse. In steep terrain, watercourses are often confined to narrow canyon areas where riparian vegetation is restricted. Broader riparian zones occur in wider valley bottoms. This warm, temperate, mid-elevational zone supports mixed broadleaf forests of Arizona sycamore (*Platanus wrightii*), Arizona walnut (*Juglans major*), velvet ash (*Fraxinus velutina*), and Bonpland willow (*Salix bonplandiana*) (Szaro 1989, Minckley and Brown 1994).

Historically, the low desert, subtropical zone riparian areas supported gallery forests of Fremont cottonwood and Gooding willow (*Salix gooddingii*). Understory communities include bosque-forming mesquite (*Prosopis*) on terraces and coyote willow (*Salix exigua*) in wetter areas. Historical records state that major rivers in the hot desert zone flowed through riparian gallery forests, densely vegetated flood plains, and substantial marshlands (Minckley and Rinne 1985).

## WILDLIFE

As forest vegetation and landscapes evolved over millennia, so did their accompanying wildlife. Little is known about the history of many wildlife species. Grass and shrub communities of the intermountain portions of the West evolved largely in the absence of large hoofed herbivores (Mack 1989). Elk (*Cervus elphus*), mule deer (*Odocoileus hemionus*), pronghorn (*Antilocarpa americana*), bighorn sheep (*Ovis canadensis*), and occasionally bison (*Bison bison*) were the dominant grazing and browsing animals. The more open canopies in woodland, ponderosa pine, and mixed conifer forests favored wildlife species such as deer, turkey, some songbirds, and small rodents. Some species such as the northern goshawk (*Accipiter gentilis atricapillus*) preferred forests with more closed canopies; others such as the Mexican spotted owl (*Sirix occidentalis lucida*) preferred habitats with vertical structure, as provided in steep canyons or tall, diverse forests.

Numerous authors (Kay 1990, 1992, 1994a, 1994b; Koch 1941; Rawley 1985) report that deer, elk, antelope, and bighorn sheep were rare or absent in the Rocky Mountains during the early 1800s. Davis (1982) reviews the status of wildlife and hunting in Arizona from 1824 to 1865. Mule deer and pronghorn were the game animals most often encountered, but hunting success was no better than today. Bighorn sheep remained in rugged mountainous districts that were avoided by early travelers so few encounters were reported. Davis (1982) goes on to state that antelope had been reduced to small scattered bands by World War I and that native elk were gone by 1900. He describes hunting in early Arizona:

> "Most of us harbor the notion that game in a virgin wilderness is always abundant, tame, and easy to kill—a hunter's paradise. No such assessment could possibly be made from the writings of the American explorers of Arizona. More often than not they complained that game was scarce and wary, and on a number of occasions several were forced to kill and eat their horses and mules."

# CHAPTER 5: CHANGES IN ECOLOGICAL PROCESSES AND FOREST CONDITIONS

"Ecosystems are dynamic entities whose basic patterns and processes were and are shaped and sustained on the landscape not only by natural successional processes, but also by natural abiotic and disturbances such as fire, drought, and wind. — Collectively, these features influence the range of natural variability of ecosystem structure, composition and function." Kaufmann et al. (1994)

This chapter describes the changes in ecological processes that occurred after the Mexican–American War in 1848 (the beginning of the Territorial Period) to the present. We discuss in particular—grazing and browsing; fire; demographics and land use; recreation; alteration of watershed processes, including erosion, stream course effects, and floods; introduction of exotic (non-native) plants; disturbance by forest insects and pathogens; timber harvest; succession; wildlife population dynamics; and air quality. How various ecosystem functions have changed within each forest community follows the descriptions of selected disturbances. The next chapter discusses how these disturbances have changed Southwestern forest ecosystems in terms of their biotic diversity, integrity and resilience, and ability to accommodate human needs.

Although climate affects forest conditions and may have shifted in the past 100 years, climate change on a global scale is beyond the scope of this assessment and is not discussed.

## GRAZING AND BROWSING

One of the earliest changes that occurred as a result of European settlement was the introduction of domestic livestock, beginning with the Spanish occupation. Juan de Onate brought sheep to the Rio Grande pueblos in 1598; cattle, horses, and goats soon followed. By 1880, cattle herds in Arizona and New Mexico were estimated at 172,000 head (Baker et al. 1988) and articles in *Western Range* reported that overgrazing was depleting the range. By 1890, cattle numbers in the Southwest increased to more than 1.5 million head; and additional large numbers of sheep were being grazed. The once lush grasslands were in danger of disappearing. The Governor of Arizona stated in 1893, "In nearly all districts, owning to overstocking, many weeds have taken the place of the best grasses" (Baker et al. 1988).

By the time forest reserves were proclaimed in 1891, ranchers had become accustomed to unregulated use of forest lands for summer range. At the turn of the century, there were so many livestock grazing the public lands that signs of range deterioration began to appear even in the "good years." In 1901, overstocking of sheep brought forest regeneration to a standstill. The forest floor in some places was "as bare and compact as a roadbed" (Baker et al. 1988):

> "They [cattlemen and sheepmen] knew nothing of grazing capacity, and there was no fund of technical knowledge about forage management to rely on. Overgrazing could not readily be recognized until in an advanced stage. Thus, when the Forest Service came into being on February 1, 1905, the most complex problems facing southwestern foresters related to grazing rights and range management."

By 1912, livestock pressures had penetrated the most remote, timbered and mountainous areas. Theodore Rixon (Roberts 1965), one of the first foresters in the Southwest, portrays the dismal situation:

> "At the beginning the mountains and heavily timbered areas were used but little, but as the situation grew more acute in the more accessible regions the use of these areas became more general and in course of time conditions within them were more grave than elsewhere... The mountains were denuded of their vegetative cover, forest reproduction was damaged or destroyed, the slopes were seamed with

deep erosion gullies, and the water-conserving power of the drainage basins became seriously impaired. Flocks passed each other on the trails, one rushing in to secure what the other had just abandoned as worthless, feed was deliberately wasted to prevent its utilization by others, the ranges were occupied before the snow had left them. Transient sheepmen roamed the country robbing the resident stockmen of forage that was justly theirs."

Not only were there pressures from range livestock but also from domestic and feral horses and burros. For over 70 years, heavy grazing reduced community diversity and plant competition; as a result there were no fine fuels to carry surface and ground fires. Grazing, reducing competition from herbaceous species, allowed rapid growth of pinyon, juniper, and oaks in adjacent communities (Nabi 1978).

The numbers of range cattle and sheep in the Southwest peaked during or shortly after World War I and have since declined (Figure 5.1). About 1920 the numbers of range cattle reached about 1.6 million head in Arizona and in New Mexico. Currently, there are 0.5 million head in Arizona and 1.2 million head in New Mexico. Sheep numbers are only available after 1920 and for New Mexico which has a substantial commercial market. Sheep populations have experienced a steady and dramatic decline from 2.3 million head in 1920 to only 0.2 million head in 1996.

Range management was one of the most difficult resource management situations for the Forest Service during its first five to six decades. Ecosystems grazed by domestic livestock, and to a lesser extent by wildlife, suffered significant damage. Only substantial investment could save some plant communities. In the early 1960s, the Forest Service began to gain some control over grazing. Since then, livestock numbers were reduced and more intensive management systems were initiated on many grazing allotments. Annual grazing reports document the decreases in permitted numbers of cattle and horses and numbers of sheep and goats in Arizona and New Mexico (Figure 5.2). Permitted numbers for cattle and horses in both states have declined by more than half their peak numbers in 1919. Sheep and goat permitted numbers are a small fraction of their 1919 levels.

At the same time that livestock numbers have decreased, populations of wild ungulates have increased. Mule deer populations and range have increased with development of stock tanks and increases of woody vegetation (Davis 1982). By 1900, elk had been extirpated in Arizona; but they were reintroduced from 1913 to 1928 by transplanting animals from Wyoming. Elk populations reached such numbers by 1995 that the annual harvest in Arizona[6] was 10,000 animals and in New Mexico[7] 12,000 animals. In some areas, such as the Apache and Gila National Forests, livestock numbers have been adjusted to respond to resource damage; but overall impacts

[6] *Unpublished data from Supplee, 1996, Arizona Game and Fish Department, Phoenix, AZ.*

[7] *Unpublished data from Goldsteine, 1996, New Mexico Game and Fish Department, Santa Fe, NM.*

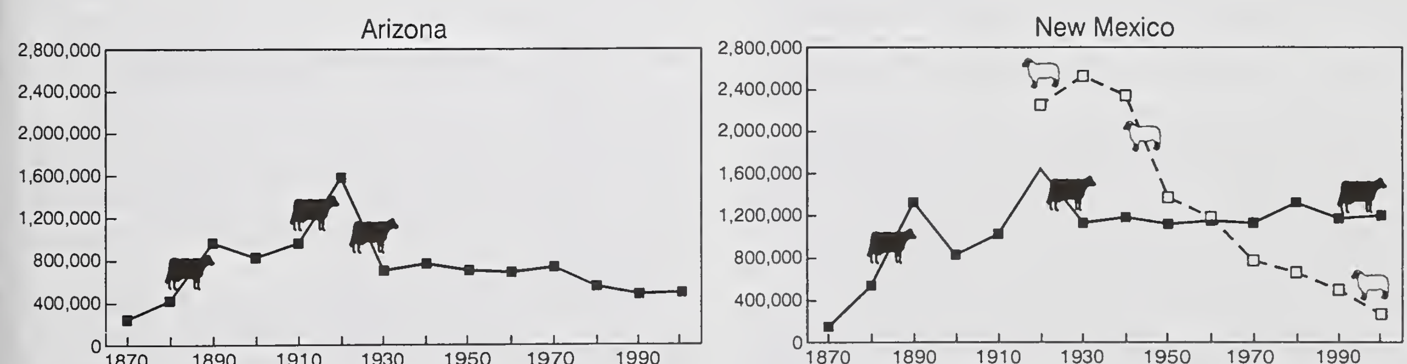


**Figure 5.1** Estimated number of range cattle and sheep in Arizona and New Mexico since 1870. Values are derived from annual, January estimates provided by the USDA National Agricultural Statistics Service, 1996. Data for numbers of sheep in Arizona and number of sheep in New Mexico before 1920 are not available. Number of range cattle is determined by subtracting the number of dairy cows and cattle on feed from the total number of cattle. Estimates for number of cattle on feed are only available after 1930, about the time feed operations in the Southwest became significant.

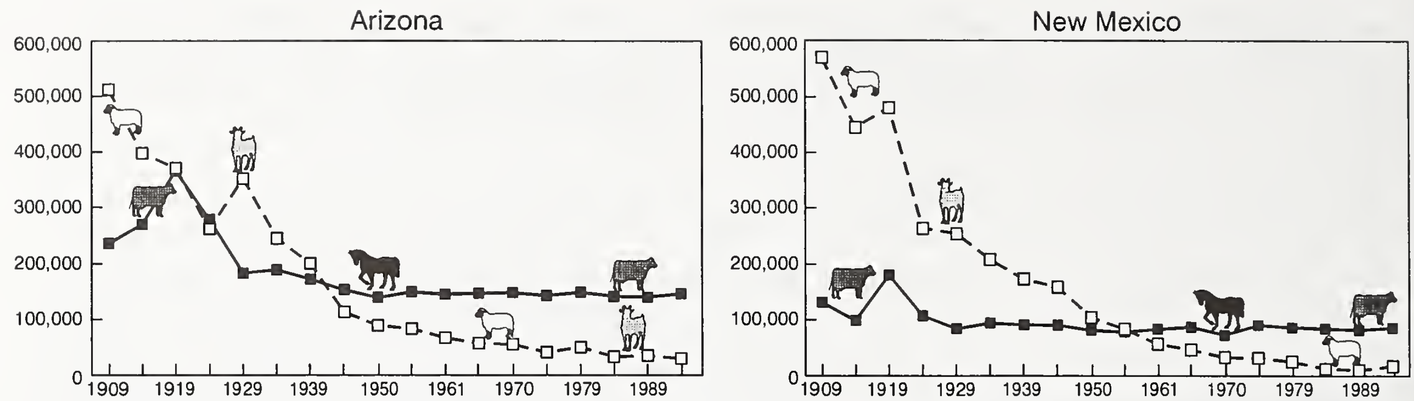


**Figure 5.2 Numbers of permitted livestock as cattle and horses and as sheep and goats in selected years from 1909 to 1992 for Arizona and New Mexico. Data provided by USDA Forest Service, Southwestern Region.**

remain the same or increase as elk subsequently move into the area. In these areas, there is much public controversy concerning whether the land should be managed for cattle or for elk.

Grazing and browsing pressures in the Southwest have changed over time, and affected the forest ecosystem both directly and indirectly. Forest ecosystems have gone from light grazing pressure during the 1800s, to severe pressure for the first several decades of this century, to current levels that attempt to balance numbers with capacity. The result of this grazing history has been to reduce the amount and diversity of the forest understory and its ability to carry surface fires.

## FIRE

Except for climate, fire probably had the largest single impact in shaping the ecology of the Southwest prior to European settlement. It continues today to be the greatest potential force controlling ecosystems. The historic fire regimes characterized in the previous chapter changed dramatically with the coming of European and American settlers. Livestock removed much of the grassy fuels that carried frequent, surface fires; roads and trails broke up the continuity of forest fuels and further contributed to reductions in fire frequency and size (Covington and Moore 1994b). Because settlers saw fire as a threat, they actively suppressed it whenever they could. Initially, fire suppression was very successful because of low fuel loadings; but without fires to consume them, fuels accumulated over time. By the early 1900s, fire exclusion began altering forest structure and fire regime (Covington et al. 1994b). Forests with historically frequent, low-intensity fires were those initially most affected (Arno and Ottmar 1993, Covington and Moore 1994a). Woodland, ponderosa pine, and drier mixed conifer forests shifted from a fire regime of frequent, surface fires to one of stand-replacing, high-intensity fires. Fire had already been infrequent but high-intensity in the spruce–fir forest, so suppression there had less effect (Covington et al. 1994a).

Fire suppression has contributed to the buildup of organic materials (fuels) on the forest floor. Logging added heavy fuels in the form of limbs, tree tops, and cull logs. In some areas, these heavy fuels have been removed by slash disposal (**fuel treatment**), **prescribed fire**, or firewood collection. The areas with the greatest fire hazard are those with the greatest fuel accumulations, such as stands never logged or logged without fuel treatment, and stands inaccessible to firewood collectors.

The disruption of natural fire regimes has decreased the diversity of stands across the landscape. Frequent fires have killed conifer seedlings encroaching into forest meadows. Fire exclusion permits this encroachment, and meadow acreage has decreased (Arno 1985, Gruell 1985). Establishment of young trees in older stands provides a fuel ladder for carrying fires into the canopy. With more stand-replacing fires, average stand age is reduced; the diversity inherent in old stands is lost.

Because of heavy fuel accumulations, fires that occur now are more intense and more difficult to contain. Certainly there are more, large fires. The number of fires burning more than 10 acres has increased each decade since the 1930's (Figure 5.3). The average size of fires since the 1970s has ranged from 14 to 16 acres per fire, double the average size of fires in earlier decades, 1940s to 1960s (Figure 5.4).

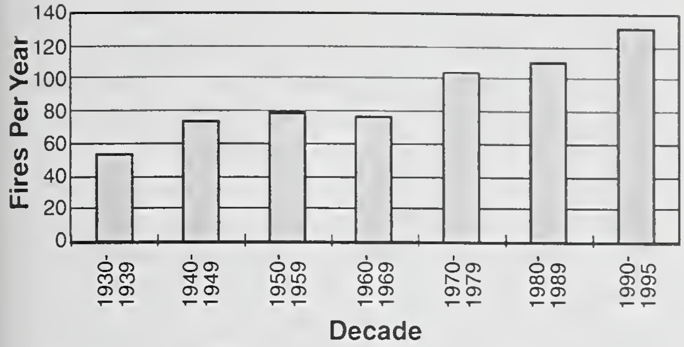


**Figure 5.3** **Average number of fires per year in the Southwest since 1930. Fires included are only those larger than 10 acres; annual data are reduced to an average for each decade or period. (USDA Forest Service 1996a).**

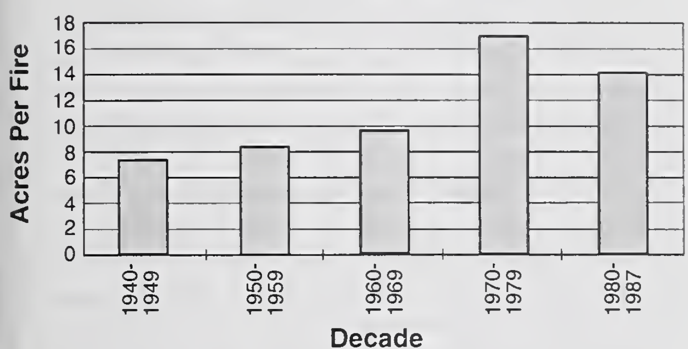


**Figure 5.4** **Average number of acres burned per fire start in the Southwest from 1940 to 1987 (Swetnam 1988)**

The role of fire in specific communities is discussed further under "Resultant Changes in Forest Condition."

## DEMOGRAPHICS AND LAND USE

It was not until the Territorial Period that both population and associated impacts on the environment increased dramatically. Population growth and resource extraction were spurred by construction of the transcontinental railroads. In the late 1870s and early 1880s, the long-awaited railroad arrived in the Southwest and linked it to population centers and commercial markets on the east and west coasts. Connections to the East promoted and expanded new industries, including sheep and cattle ranching, mining, and timber. The railroads supported population growth through homesteading and employment for construction and operations. The exploitation of minerals, grasslands, and forests as part of the new, commercial economy opened the Southwest to more intensive use than the preceding, subsistence economy had found possible or necessary. The new Southwestern settlers introduced changes to the economy that altered settlement and land use patterns, along with natural resources. The consequences were depletion of forage, degradation of riparian areas, and changes to water tables, forest communities, wildlife habitats, and wildlife populations (de Buys 1985, Bahre 1991). The centuries-old system of irrigation farming with **acequias** had changed little before the 1920s; frustrated by antiquated farming methods, the new settlers introduced "modern" farming approaches and techniques.

Within decades of the arrival of the railroad, the population of the Southwest increased rapidly. Population levels soon exceeded the carrying capacity of the land using only traditional technologies. To meet subsistence and economic needs, new practices in farming, irrigation, ranching, and timber harvesting were initiated. Resource extraction increased exponentially, not only for use within the Southwest but also for export throughout the United States. Consequently, resource demands exceeded the system's capacity of renewal and led to unsustainable practices such as—the excessive trapping of beaver from the early 1800s, overuse of forage by domestic livestock from the mid-1800s, and depletion of old-growth trees and forests in this century (Covington and Moore 1994a, Johnson 1994, Allen 1989, Cooper 1960, Dick-Peddie 1993). Extensive and unregulated mining led to degradation of upland slopes, riparian areas, and streams. Hydroelectric dams, over-harvesting, and loss of habitat impacted fisheries. Once-flowing streams were de-watered to satisfy irrigation needs.

Especially in the past few decades, the population of the Southwest has boomed and become more urban. The population of Arizona first exceeded that of New Mexico in the 1930s; since then Arizona has grown more quickly than New Mexico and by 1960 surpassed a million (Figure 5.5, data from de Gennaro 1990, Vest 1996, Bureau of Business and Economic Research 1994). If expected trends continue, by 2010 there will be two million people in New Mexico and three times as many in Arizona. The majority of residents live in the most urban counties of each state (those with the largest cities). Maricopa County (including Phoenix) has a population of 2,355,900; and

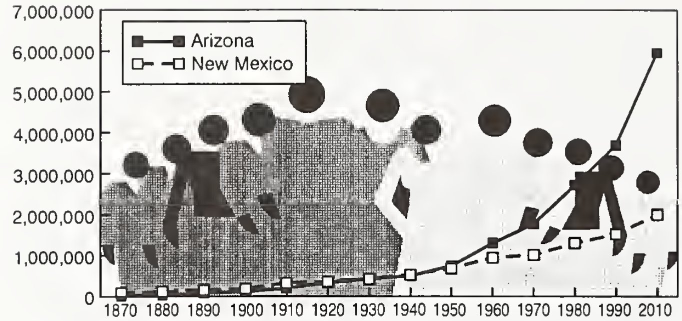


**Figure 5.5 Population growth in Arizona and New Mexico 1870-1990 and projected population for the year 2010. (de Gennaro 1990, Vest 1996, Bureau of Business and Economic Research 1994).**

Bernalillo County (including Albuquerque) has 650,000 residents.

## RECREATION

The transcontinental railroads not only opened the Southwest for resource extraction and settlement, but also opened a market for tourism. In the last quarter of the 19th century, the Santa Fe Railroad expanded its ridership through tourism to the Grand Canyon in Arizona and the Indian pueblos in New Mexico. In its efforts to encourage tourism of the Southwest, the railroad was aided and assisted by the Fred Harvey Company (Howard and Pardue 1996):

> "The Fred Harvey Company and the Santa Fe Railway joined forces at an auspicious historical moment. Borrowing new techniques in marketing and advertising, the companies promoted the American Southwest as an exotic destination. The railroad, the travelers, and the indigenous communities of the region were all integral elements in a partnership that spanned more than three-quarters of a century."

Still, much of the recreation potential of Southwest remained undiscovered. Only the most spectacular sites that were easily accessible from the railroads attracted significant visitation. Recreation facilities and services in most of the region's arid landscape were sparse and primitive, simply because there was little demand before 1940 (USDA Forest Service 1980):

> "Recreation use of the forest reserves grew slowly at first, then more rapidly as automobiles became numerous and roads penetrated further into what had previously been remote and inaccessible areas. General prosperity and more leisure time increased the human flow into the national forests, a flow which eventually became a flood."

Beginning in the 1970s, the Southwest was "discovered." The population expansion of the Phoenix and Tucson metropolitan areas was unparalleled anywhere in the United States. At the same time, the mystique of the "Land of Enchantment" and the "Santa Fe" style captured the attention of trend-setters throughout the country, and tourism to New Mexico exploded. Because of the mild weather, the Southwest also became a winter mecca for retired people as well as those with the freedom of long vacations. The Southwest became the nation's number-one target destination for the retired and recreational vehicle (RV) traveler, making it a year-round recreation area.

The Southwest has a diversity of high-quality recreation opportunities ranging from the primitive settings of the Gila Wilderness (first wilderness in the National Forest System) to the urban settings of the Salt River Chain of Lakes outside of Phoenix, Arizona. With the large increase in population and the attraction of the Southwest's climate, culture, and scenery, recreation use has increased tremendously over the past 20 years. Recreation use (as recreation-visitor-days, **RVD**, see glossary for defination) on National Forest System lands since 1965 has increased fourfold:

| Year | Recreation–visitor–days |
|---|---|
| 1965 | 10,147 |
| 1976 | 15,565 |
| 1985 | 21,742 |
| 1996 | 44,342 |

### Developed Site Recreation

There has been an increase in demand for high-quality developments that include toilets, showers, lights, and reservation systems. Modern campers are seeking spaces designed for 40-foot RVs with individual hookups for sewage, water, power, and cable television. They also want trails, mountain bike paths, and interpretive nature walks. Their expectations on safety and security far surpass traditional offerings. The effects on forest health of this localized use include soil compaction, loss of vegetative cover, and soil erosion.

## Wilderness

At the other end of the spectrum, there has been an increase in numbers seeking solitude in back-country and wilderness areas. The idea, concept, and spirit of wilderness found their beginning in the Southwest. Heroes of the wilderness movement, Arthur Carhart and Aldo Leopold, worked in New Mexico and were influential in creating the first administratively designated wilderness, the Gila. The Forest Service in the Southwest now administers 52 designated Wildernesses with a combined total of 2,736,500 acres and an additional 175,112 acres in the Blue Range Primitive Area. These areas are ecologically diverse and range in size from 5,200 acres to 558,065 acres. Some are adjacent to the major cities of Phoenix, Tucson, and Albuquerque. These present complex management situations of protecting the resource from overuse, and resolving issues of non-conforming uses such as structures, illegal motorized access, overflights, and cultivation of cannabis. With more and more people using wildernesses there has been a noticeable effect on forest health including introduction of exotic weeds and an increase in human-caused fires. From 1992 through 1996, there were 18,747 human-caused fires in the Southwest (all ownerships) compared to 12,988 lightning-caused fires.

## Heritage Sites

Of all the many tourist destinations in the West, few combine the landscapes and the romance of the Western experience as strikingly as the archaeological ruins of the Southwest. A recent study of heritage tourism by the New Mexico Office of Cultural Affairs (1995) indicates that visiting heritage sites and learning about American Indian culture ranked second only to scenic beauty, and higher than outdoor recreation, in reasons given for why people visit the state. Similar findings have been reported by Kaufman[8] for Arizona. In a market overview of the Four Corners region, sightseeing at cultural and historic sites was noted as the number one purpose of trips to the area (Lillywhite 1994). In New Mexico alone, over 12 million visits are made each year to heritage sites and events, and the total economic impact of heritage resources is estimated to be $1.6 billion.

[8] *Tourism and archaeology in Arizona: assessing the economic impacts; unpublished manuscript dated 1996 on file Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region.*

Interest in the heritage resources on national forests is increasing as people seek out opportunities to discover and explore Southwestern cultures in more remote, uncrowded settings. Over 50,000 heritage sites have been inventoried on national forests in Arizona and New Mexico. These include cliff dwellings, massive pueblo ruins, and a vast array of other historic and prehistoric remains. Heritage sites hold important cultural, educational, and scientific values for many people and contain clues for reconstructing prehistoric landscapes and past ecosystems. Many of these sites are threatened by natural and human forces, including erosion, vandalism, and the cumulative effects of visitation. Southwestern Indian tribes continue to express concern about the protection and appropriate use of these resources. Experience gained through programs like "Passport in Time" shows the public is eager for opportunities to assist in the preservation and study of heritage resources. Balancing the public's desire to experience the past with the exigency of protecting sites and the need to be sensitive to tribal concerns is an important challenge.

## River Use

Another example of the public's attraction to the Southwest is reflected in the tremendous growth of whitewater river use during the past five years. Rafters, canoeists, and kayakers, both individually and through outfitter guide services, have discovered that the Southwest has miles of fine whitewater and attractive riparian habitats. As a result, river management needs to balance increased use with a need to protect the ecosystem on which the use is dependent. River use brings new health issues including disposal of human waste, water pollution, litter, and wildlife disturbance.

## Hunters, Anglers, and Wildlife Viewers

The diversity of wildlife in the Southwest has attracted large numbers of hunters, anglers, and wildlife viewers. The Southwest serves as a major staging and stopover area for great numbers of migrating North American waterfowl. Only in the

Southwest can four species of quail (*Lophortyx*) be found and hunted. Arizona and New Mexico are known for the last of the really great trophy elk as well as two kinds of bighorn sheep (desert and mountain). Other major game species are deer, black bear (*Ursus americanus*), pronghorn, mountain lion (*Felis concolor*), javelina (*Tayassu tajacu*), wild turkey, doves, grouse, and squirrel. In 1991, approximately 291,000 hunters spent 2.6 million days (8 hour days) pursuing game in Arizona and New Mexico (compiled data from various federal and state statistics). Fishing is an even more popular activity in the Southwest with 761,000 anglers and 6 million fishing days estimated for 1991 alone (same data sources as above). The major species taken are bass, trout, catfish, crappie, and sunfish. But the most popular activity, undertaken by 1.6 million people (9.2 million days in 1991), was observing and photographing the over 500 species of birds found in the Southwest.

### Outfitter Guide Services

Outfitter and guide permits are issued for a variety of recreational pursuits. These include special events, horseback and llama-supported wilderness trips, jeep tours of backcountry areas, big game hunting, caving, whitewater rafting, and environmental awareness training. Many exotic types of dispersed recreation activities, which are provided by the private sector, such as bungee jumping, rock climbing, hang gliding, scuba diving, gold panning, and caving continue to gain in popularity, and pose unique, new management challenges. Major impacts of these newer uses tend to be concentrated in the same areas as the more traditional activities such as hiking, biking, off-highway vehicle (**OHV**), water-oriented recreation, and horseback riding. Conflicts are on the rise in a region where there was once sufficient land capacity to accommodate all requests. The challenge is to find a sustainable balance.

### Winter Use

Winter sports activities include destination, alpine ski areas such as Taos Ski Valley, Santa Fe Ski Area, Arizona Snow Bowl Ski Area and several Nordic ski centers. There are 10 alpine ski areas wholly or partially on national forest lands. In 1990, use on these areas totaled 620,000 RVDs with over a million ski visits. Ski resorts have significant, although local, impacts on the land. In addition, cross-country skiing, snowmobiling, and tubing attract many people.

### Recreation Impacts

Many years ago, the numbers of people recreating on the national forests were so few and undemanding that they were little burden on the land. Now, people come in such great numbers and with such a wide variety of demands that their presence has brought significant impacts. Negative impacts include introductions of exotic weeds, increased human-caused fires, vandalism, littering, and stealing the artifacts of ancient human cultures. On the positive side, recreationists stimulate local economies and the tourism industry and provide numerous social and psychological benefits to themselves, their families and communities. Finally, as a result of their use and enjoyment of the forest, recreationists increase their awareness and possibly their involvement in forest health issues.

## WATERSHED PROCESSES

Grazing and browsing, which reduced the ground cover of grasses and litter and reduced the frequency of fires, have also changed hydrologic cycles. Reduction in fire frequency has resulted in increased density of trees in most forest communities. Increased tree density has increased transpiration and interception of precipitation thereby making less water available for long-term stream flow. On the other hand, soil compaction caused by grazing of domestic and wild animals slows infiltration of surface water. Construction of roads increases runoff through interception and concentration of surface flows. These factors taken together can generate rapid runoff and powerful floods. Although total stream flow is reduced by increased evapotranspiration, periodic floods may generate peak flows greater than historic levels. Flooding occurs because water runs off the surface rapidly rather than being absorbed into the soil and released slowly to the watercourse. A flood may be powerful enough to remove the entire flood plain and its riparian vegetation. Floods may also cut deep, incised channels through old alluvial deposits. In a wet meadow, this channel cutting can lower the water table and drain hydric soils.

Impoundments and diversions on large rivers significantly modify the channel dynamics of erosion and deposition. The regeneration of cottonwoods and willows is dependent on natural floods to create seedbeds and moist conditions required for germination and establishment. Below large flood control dams, floods that would have supported this regeneration no longer occur.

Because arroyo formation in the late 19th century coincided with high livestock numbers, overgrazing has been portrayed as the primary cause of arroyos in the Southwest. However, cycles of arroyo cutting and filling have occurred repeatedly since prehistoric times (Cooke and Reeves 1976, Dean et al. 1985). Prehistoric arroyos are usually attributed to climatic variations. But, identifying the cause of arroyo formation in historic times has been difficult. Hastings and Turner (1965) and Cooke and Reeves (1976) conclude that arroyos probably arose from several interrelated environmental changes, including rainfall pattern, moisture regime and vegetation change. Although human-induced land disturbance may have played a role in arroyo formation, it was probably neither the sole nor primary cause. Apparently, various combinations of initial conditions and environmental changes can form similar appearing arroyos in different areas (Cooke and Reeves 1976).

## INTRODUCTION OF EXOTIC PLANTS

In the early to mid 1800s, European and Asian immigrants to the Southwest brought from their native lands not only animals and material items but also various ornamental plants and plants of cultural significance. In their native environment, these plants had been subject to control by various insects and diseases not present in America. In their new home, these plants were carefully cultivated; many found a suitable climate in which they could thrive even without care. By the early 1900s, the most aggressive species were out of control. Many were causing economic losses by competing with desirable plants, poisoning animals, hosting insect and disease agents, and altering various ecosystem attributes, such as fire regime (Dick-Peddie 1993).

Exotic weeds continue to invade rangelands, forests, and riparian ecosystems at an alarming rate. Control of infestations has been difficult, and the ecological consequences have been serious. The rapid expansion of exotic weed populations is a great deterrent, if not the greatest deterrent, to restoring native plant communities and re-establishing historic conditions. If exotic plants are not kept in check, long-term devastating effects to forest ecosystems can occur. The ecological effects include replacement of native plant species and reduction in ground cover which leads to loss of biodiversity, forage, habitat and scenic quality, and even **soil productivity**.

The Forest Service **noxious weed** strategy provides short-term direction for the containment, control, and management of noxious weeds through the Federal Noxious Weed Act of 1974, the 1990 Farm Bill Amendment, and USDA Departmental Regulation 9500–10. Species which are aggressive, difficult to control, toxic, parasitic, or hosts to serious disease or insect pests may be designated as noxious weeds. The Arizona Interagency Noxious Weed Committee has designated 37 native and exotic species as noxious weeds (Table 5.1); the New Mexico Interagency Noxious Weed Committee has designated 21 exotic species (Table 5.2).

## FOREST INSECTS AND PATHOGENS

Forest insects, fungi, and parasitic plants continue to play important ecological roles in the re-structuring of forest communities (Holling 1992). The tree mortality that results directly or indirectly from their activity provides habitat, promotes nutrient cycling, drives plant succession, and contributes to biological diversity. Although their fundamental roles remain unaltered since historic times, the frequency, extent, or synchroneity of outbreaks may have changed for some of these disturbance agents. Insect and pathogen populations are ultimately limited by the availability of susceptible host trees. Therefore, changes in stand density, composition, and structure caused by fire suppression and logging would likely have affected outbreak patterns. Disturbance regimes of native insects and pathogens may also be affected by the introduction of exotics such as white pine blister rust (*Cronartium ribicola*). Detailed, standardized, regional reports of annual insect and disease conditions are available for only the past 25 years. Before then, reports[9] of forest insect and disease activity were sporadic and emphasized situations where valuable economic or visual resources were threatened. In spite of limited information prior to 1900, there are good descriptions of more recent outbreaks and epidemics.

[9] *Forest insect conditions, R-3, 1918-1952; photocopied letters and annual reports on file; Flagstaff, AZ: U.S. Department of Agriculture, Forest Service, Arizona Zone Entomology and Pathology.*

**Table 5.1 Designated noxious plants of Arizona.**

| Scientific name | Common name | Origin | Life Cycle |
|---|---|---|---|
| *Aegilops cylindrica* | Jointed goatgrass | So. Europe | Annual |
| *Alhagi pseudalhagi* | Camelthorn | Asia | Perennial |
| *Ambrosia trifida* | Giant ragweed | Native | Annual |
| *Asclepias subverticilla* | Poison milkweed | Native | Perennial |
| *Asphodelous fistulosus* | Onion weed | Mexico | Perennial |
| *Cannabis sativa* | Marijuana | Asia | Annual |
| *Cardaria chalepensis* | Lens-podded hoary cress | Eurasia | Perennial |
| *Cardaria draba* | Whitetop or hoary cress | Eurasia | Perennial |
| *Cardaria pubescens* | Globe-potted hoary cress | Eurasia | Perennial |
| *Carduus nutans* | Musk thistle | So. Europe | Biennial |
| *Centaurea calcitrapa* | Purple starthistle | Europe | Annual |
| *Centaurea diffusa* | Diffused knapweed | Eurasia | Perennial |
| *Centaurea repens* | Russian knapweed | Eurasia | Perennial |
| *Centaurea maculosa* | Spotted knapweed | Eurasia | Perennial |
| *Centaurea solstitialis* | Yellow starthistle | Europe | Annual |
| *Cirsium arevense* | Canada thistle | Eurasia | Perennial |
| *Cirsium vulgare* | Bull thistle | Eurasia | Biennial |
| *Convolvulus arvensis* | Field bindweed | Europe | Perennial |
| *Drymaria arenarioides* | Alfombrilla | Mexico | Perennial |
| *Echhornia azurea* | Anchored waterhyacinth | Brazil | Perennial |
| *Euphorbia esula* | Leafy spurge | Eurasia | Perennial |
| *Halogeton glomeratus* | Halogeton | Asia | Annual |
| *Hydrilla verticillata* | Hydrilla | So. Africa | Perennial |
| *Hymenoxys richardsonii* | Pinque | Native | Annual |
| *Kochia scoparia* | Kochia | Asia | Annual |
| *Linaria dalmatica* | Dalmation toadflax | Europe | Perennial |
| *Linaria vulgaris* | Yellow toadflax | Eurasia | Perennial |
| *Onopordum acanthium* | Scotch thistle | Europe | Biennial |
| *Rorippa austriaca* | Austrian field cress | Eurasia | Perennial |
| *Salsola iberica* | Russian thistle | Russia | Annual |
| *Solanum carolinense* | Carolina horsenettle | Native | Perennial |
| *Solanum elaeagnifolium* | Silver nightshade | Native | Perennial |
| *Sonchus arvensis* | Perennial sowthistle | Eurasia | Perennial |
| *Sorghum halepense* | Johnson grass | Mediterranean | Perennial |
| *Tribulus terrestris* | Puncture-vine | So. Europe | Annual |
| *Verbascum thapsus* | Mullein | Asia | Biennial |
| *Zigadenus paniculatus* | Death camas | Native | Perennial |

Native and exotic plants listed by the Arizona Interagency Noxious Weed Committee for their poisonous or invasive properties.

## Bark Beetles

The known outbreak history of the roundheaded pine beetle in the Sacramento Mountains in southeastern New Mexico suggests an increasing trend during this century. At least six outbreaks have been reported in the Sacramento Mountains since 1937 (Bennett et al. 1994). From 1937 to the late 1960s, these outbreaks involved small acreages. In the early 1970s, an estimated 400,000 second-growth ponderosa pine trees were killed over 150,000 acres (Massey et al. 1977). This outbreak killed between 11 and 54 percent of ponderosa pines in sampled stands (Stevens and Flake 1974). Although the average diameter of ponderosa pine before and after the outbreak was unchanged, species dominance shifted to Douglas-fir and white fir. In the early 1990s, another outbreak of both the roundheaded pine beetle and the western pine beetle killed an estimated 100,000 trees over 87,000 acres. About the same time, two smaller yet still significant outbreaks of roundheaded pine beetle occurred in the Pinaleno Mountains of southeastern

**Table 5.2 Designated noxious plants of New Mexico.**

| Scientific name | Common name | Origin | Life Cycle |
|---|---|---|---|
| *Alhagi pseudalhagi* | Camelthorn | Asia | Perennial |
| *Cardaria draba* | Whitetop or hoary cress | Eurasia | Perennial |
| *Carduus nutans* | Musk thistle | So. Europe | Biennial |
| *Centaurea calcitrapa* | Purple starthistle | Europe | Annual |
| *Centaurea diffusa* | Diffused knapweed | Eurasia | Perennial |
| *Centaurea maculosa* | Spotted knapweed | Eurasia | Perennial |
| *Centaurea melitensis* | Malta starthistle | Europe | Annual |
| *Centaurea repens* | Russian knapweed | Eurasia | Perennial |
| *Centaurea solstitialis* | Yellow starthistle | Europe | Annual |
| *Cirsium arvense* | Canada thistle | Eurasia | Perennial |
| *Cirsium vulgare* | Bull thistle | Eurasia | Biennial |
| *Dipsacus sylvestris* | Teasel | Europe | Biennial |
| *Euphoria esula* | Leafy spurge | Eurasia | Perennial |
| *Halogeton glomeratus* | Halogeton | Asia | Annual |
| *Hydrilla verticillata* | Hydrilla | So. Africa | Perennial |
| *Lepidium latifolium* | Perennial pepperweed | So. Europe | Perennial |
| *Linaria dalmatica* | Dalmation toadflax | Europe | Perennial |
| *Linaria vulgaris* | Yellow toadflax | Eurasia | Perennial |
| *Lythrum salicaria* | Purple loosestrife | Europe | Perennial |
| *Onopordum acanthium* | Scotch thistle | Europe | Biennial |
| *Peganum harmala* | African Rue | No. Africa | Perennial |

Exotic plants listed by the New Mexico Interagency Noxious Weed Committee for their poisonous or invasive properties.

Arizona (Flake 1970, Wilson 1993); no prior outbreaks in the area are known. At least for these two areas, increases in outbreak size and frequency may have resulted from changes in stand conditions, especially increased density of susceptible host trees.

Elsewhere in the Southwest, large pine-beetle outbreaks have occurred only on the Kaibab Plateau (Colorado Plateau Province). A mountain pine beetle outbreak in this northern Arizona forest covered over 75,000 acres at its largest extent in the mid- to late-1970s. Otherwise, outbreaks in the pine forests have generally been less extensive and of shorter duration. The susceptibility of the pine communities to bark beetles, however, continues to increase slowly over time so larger, more severe outbreaks may occur in the future.

In other pine forests and in mixed conifer forests, extensive, sustained outbreaks have been rare, even though stands there are at historically high levels of risk due to increased tree densities.

Large, spruce beetle outbreaks occurred in northern New Mexico, the Jemez Mountains during 1970s and the Pecos Wilderness between 1982 and 1985, and in Arizona, the White Mountains in the 1980s (USDA Forest Service 1976, Bennett et al. 1994). Infrequent, large outbreaks, however, are considered typical of natural disturbance regimes in spruce–fir forests (Veblen et al. 1994, Schmid and Frye 1977).

### Western Spruce Budworm

Although the frequency of western spruce budworm outbreaks has not changed in this century compared to the past, their spatial and temporal pattern has changed (Swetnam and Lynch 1989, 1993). The most recent outbreaks in northern New Mexico (Southern Rocky Mountain Province) have been more synchronous and therefore more extensive and perhaps more severe than previous outbreaks. Fire suppression, grazing, and harvesting preferences to remove pines have favored establishment of multistoried stands of young shade-tolerant species that are preferred hosts for the budworm. These changes in forest composition and structure may well account for the observed changes in budworm outbreak patterns.

### Root Decay Fungi

A recent survey of commercial timber-producing lands on six national forests in Arizona and New Mexico (Wood 1993) indicates that root diseases and associated pests are responsible for mortality of 34 percent of trees (> 5 inches **dbh**). Although it is impossible to determine whether the relative importance of root disease as a mortality factor has increased recently, it is likely that root disease fungi are responding to the greater abundance of host material (living and dead). Species conversion allows new opportunities for host-preferring fungi; increased tree density permits greater root contact; increased competition and insect activity further weakens trees; and more stumps provide additional and long-lasting sources of inoculum. The life histories of root disease fungi and bark beetles complement each other as a positive feedback system that could potentially lead to larger and more persistent outbreaks. The extent or distribution of root disease is also likely to expand to those areas where Douglas-fir and white fir have recently replaced ponderosa pine (Johnson 1994).

### White Pine Blister Rust

White pine blister rust is caused by the fungus *Cronartium ribicola*, introduced in the Northwest about 1910. The fungus has spread across the coastal and northern states and has caused serious economic and ecological impacts on western white pine (*Pinus monticola*), sugar pine (*P. lambertiana*), and whitebark pine (*P. albicaulis*). In 1990, the rust was discovered in the Southwest on southwestern white pine (Hawksworth 1990); the rust probably first became established about 1970 near Cloudcroft, New Mexico. Surveys indicate the rust is now present throughout the Sacramento Mountains (Hawksworth and Conklin 1990) and adjacent Capitan Mountains. The fungus rapidly kills seedlings and saplings. Larger trees are initially flagged (infected branches killed); later, the bole is cankered and eventually girdled. Because southwestern white pine is highly susceptible and environmental conditions are especially suitable in the Sacramento Mountains, the epidemic is expected to severely impact the white pine population there. A large inoculum source in the Sacramento Mountains increases the threat to other white pine populations in the Southwest and northern Mexico. The loss of southwestern white pine from the mixed conifer forests of the Sacramento Mountains not only reduces species diversity but also may result in greater damage by other disturbance agents.

### Dwarf Mistletoes

More than 2 million acres of national forest lands in the Southwest are currently infested with dwarf mistletoes (Johnson and Hawksworth 1985). Surveys of ponderosa pine forests conducted in the 1950s and 1980s suggest that the incidence of southwestern dwarf mistletoe in ponderosa pine may have increased in some areas due to past fire suppression and timber harvesting (Andrews and Daniels 1960, Maffei and Beatty 1988). Although basic principles of mistletoe control have long been known (Koristian and Long 1922, Pearson 1950), intermediate cutting practices that leave infected trees and infrequent use of final removal cuts and understory sanitation may have increased mistletoe abundance. Fire suppression may also have resulted in the retention of additional infected trees that serve as inoculum sources to the developing understory. Because mistletoe spreads rapidly from overstory to understory trees, improper use of uneven-aged management could also increase mistletoe abundance. Dwarf mistletoe is a native member of the plant community, and it provides numerous ecological benefits where host–pathogen levels are within a natural range. Unfortunately, present forest conditions are especially suitable for development of infestation levels not previously experienced in these forests. A consequence of greater infestation is an increase in the risk and severity of insect outbreaks and wildfire.

## TIMBER HARVEST

Logging has been conducted in the Southwest for over 100 years. Major efforts began with the harvest of railroad ties and other products for construction of the transcontinental railroad in the 1870s and 1880s (Schubert 1974). During the early days, logs were removed from the forests by expensive rail transport. To make these operations economically feasible, 70 to 80 percent of the volume had to be removed (Schubert 1974). When trucks became available for hauling, lighter cuts became economical. To insure continued timber supplies until young trees could establish and grow to adequate size, harvests of large trees were further reduced by distributing the cut to two or more entries (Myers and Martin 1963). During this time, typical harvests removed one-third to two-thirds of the available volume (Myers and Martin 1963) and averaged about 50 percent (Schubert 1974). At these residual stocking rates, reproduction was good to excellent (Schubert 1974), so stem density increased while tree size and age deceased.

Logging in the Southwest has been practiced over many acres with various methods and associated activities. Harvest practices have ranged from **high-grading** which removed quality trees and left poor trees to clearcutting and group selection which established even-aged stands or clusters of vigorous trees. The result has been a number of different environmental effects, good or bad, that vary from site to site. Although not a universal practice, logging slash is commonly piled and burned. The effect of this treatment is to reduce habitat for small mammals and material that might have contributed to soil organic content (Harvey et al. 1987). Where this treatment was not used, habitat and soil organic material increased, but so also did fire hazard.

Timber harvest levels on National Forest System lands in the Southwest have been tracked since 1908. Harvest levels gradually increased through the 1950s and, under sustained–yield management, remained relatively flat through the 1980s:

| Decade | Average annual cut, million board feet |
|---|---|
| 1908–1910 | 40 |
| 1911–1920 | 76 |
| 1921–1930 | 87 |
| 1931–1940 | 98 |
| 1941–1950 | 178 |
| 1951–1960 | 275 |
| 1961–1970 | 396 |
| 1971–1980 | 375 |
| 1981–1990 | 402 |

There has been an steady decline in the amount of timber cut in the 1990s. The timber cut in 1996 was almost exclusively fuelwood:

| Year | Annual cut, million board feet |
|---|---|
| 1991 | 344 |
| 1992 | 291 |
| 1993 | 190 |
| 1994 | 115 |
| 1995 | 100 |
| 1996 | 46 |

The net annual growth rate of all size classes of saw timber in the Region, currently around 700 million board feet, is substantially greater than historic harvest levels (Johnson 1994).

Roads associated with logging have made human access to the forest easier. This has several effects, including improved fire fighting efficiency, increased recreational use, and easier access to fuelwood. Roads, however, also provide better access for poachers and may increase habitat fragmentation for some species. Improperly located roads can result in increased soil erosion, stream siltation, and meadow degradation.

Through the harvest of dead and dying trees, the number of snags may have been reduced in some areas. Snags are important habitat components for some wildlife species. On the other hand, logging has occasionally been used to reset succession to an early stage for the benefit of specific plants and animals adapted to these conditions.

Harvesting fuelwood in woodlands has resulted in removal of many of the larger trees in some areas. The combined effects of removal of large trees, intensive grazing, and fire exclusion have resulted in extremely dense stands in some forests. The dense cover of trees and grazing pressure have reduced the density of grasses and forbs, resulting in increased rates of soil erosion over large areas.

## SUCCESSION

Plant succession and disturbance are now recognized as closely connected processes that together determine vegetation dynamics. This section focuses on forest succession, the factors affecting it, and the resulting vegetation patterns and ecological consequences.

### Definitions and Theories

Following a disturbance that kills or removes a significant portion of the dominant vegetation, succession is the recolonization and replacement of plant species that occupy and eventually dominate a site. Characteristic sequences of species (**seres**) develop. Early dominants modify environmental conditions, that affect subsequent immigration and reproduction. Succession continues until a regional and climatic climax develops. Various ecological mechanisms drive the process (McCook 1994), and succession may follow various pathways at varying rates and directions (Hagle and Williams 1995, McCune and Allen 1985). Although climax species are able to reproduce under conditions they create, further disturbance is common every-where so a climax community may never develop on some sites (van der Maarel 1993). Succession is usually seen as species turnover, but it can also be described as changes in physiognomy or ecosystem processes. Forest succession characteristically proceeds through four physiognomic stages—stand initiation, stem exclusion, understory re-initiation, and **old growth** (Oliver 1981). As succession proceeds, ecosystem processes such as nutrient cycling progress through phases of exploitation and conservation; Holling (1992) integrates disturbance into this model by adding two short but critical phases, release and reorganization.

Succession is a fundamental process operating at a fine scale. Together with disturbance that can operate at a range of scales, these processes determine vegetation dynamics from single-tree canopy gaps to forest landscapes (Delcourt et al. 1983, Holling 1992). Succession is a gap and patch scale process because it is the result of various tree-to-tree interactions such as competition and **allopathy** (Shugart 1984, Watt 1947). Coarse-scale landscape patterns arise from the replication of these patches over large areas. Turner et al. (1993) describe a conceptual model that integrates disturbance and succession on both spatial and temporal scales. The temporal dimension is represented as the ratio of time between disturbance events and time required for recovery; the spatial dimension is represented as the ratio of area disturbed to total landscape area. Various regions on this spatial-temporal graph identify where the interactions of disturbance and succession lead to landscape stability, oscillation, or destruction. Veblen et al. (1994) provide a more concrete example of disturbance–succession interactions using observations from a spruce–fir forest. They describe a complex pattern of vegetation patches as the outcome of snow avalanches, fire, and spruce beetle acting on two tree species, subalpine fir and Englemann spruce, with very different survival and reproduction strategies.

Competing theories by Clements and Gleason were proposed early this century to explain succession (see reviews by McIntosh 1980, McCook 1994, Cook 1996). Clements (1916) emphasizes the importance of competition and the effect of vegetation on modifying environmental conditions ("reaction"). He argues that succession proceeded unidirectionally to commonly occurring self-replicating stages characteristic of a region and climate (climax vegetation). He discounts the role of disturbance and thought that before settlement most sites supported climax vegetation. These ideas were repeated in many early textbooks and once widely accepted; but later evidence has accumulated to challenge this simple, deterministic explanation (Drury and Nisbet 1973). The alternative theory presented by Gleason (1926) recognizes greater significance of individual species differences (life history) and chance events (variation in seed source). With modification and elaboration, these ideas became incorporated into many subsequent theories and models of succession. Numerous studies confirm the importance of life history and disturbance on succession.

The differences between Clements (1916) and Gleason (1926) opened a debate on succession that has continued throughout the century. Tansley (1935) proposes that more than one climax may result on a given site. Watt (1947) identifies the importance of patches and disturbance cycles for creating vegetation mosaics. Egler (1954) notes that species did not always invade a site in relay but may be initially on the site and sequentially assume dominance. Pickett (1976) recognizes the importance of natural selection and disturbance. Connell and Slatyer (1977) propose three alternative mechanisms of species interaction for driving succession—facilitation, tolerance, and inhibition. Grime (1979) expands on explanations of succession due to life history characteristics and recognized three strategies—**ruderal** (in early stages), competitive (in middle stages), and stress–tolerant (at later stages). Cattelino et al. (1979) further refine the life history concept and integrated succession with disturbance regime; they demonstrate the possibility of multiple outcomes on a single site. Huston and Smith (1987) construct a general simulation model to explore species interactions and successional pathways. Expanding on the mechanisms of Connell and Slatyer (1977), Huston and Smith (1987) demonstrate how five successional patterns could emerge: sequential succession, divergence, total suppression, convergence, and pseudo-cyclic replacement. A number of books (e.g., Glenn-Lewin et al. 1992) provide a modern synthesis of successional theories that tend to be mechanistic (Shugart 1984) rather than holistic and to allow for non-equilibrium (chaotic) cycles (Oliver and Larson 1990) rather than require stable, deterministic outcomes.

### Factors Affecting Succession and Resulting Patterns

The principal factors that determine the direction and rate succession are climate, site conditions (such as landform, elevation, and soil), and life history strategies. Various random influences (e.g., initial species mix and invasion opportunities) and disturbances also have a significant effect on succession (McCune and Allen 1985).

Climate, site conditions, and life strategies usually evolve slowly relative to successional rates, although there are exceptions. Climatic change has been relatively gradual throughout the present interglacial period; but future climatic warming could be more rapid (Delcourt et al. 1983). Pearson (1931) not only describes climate and forest types across the Southwest, but he also relates vegetation and soils. For example, he observes that substrates such as those with high clay content can be detrimental to pine reproduction and therefore limit the potential vegetation on a site. Because soils that develop in prairies are distinct from those that develop in forests, it is sometimes possible to determine that trees have recently invaded or retreated from an area. Life history strategies are the product of evolution and represent the integration of numerous physiological and morphological adaptions. Especially for long-lived trees in tightly connected ecosystems, life history attributes of a species probably change only very gradually most of the time. Rapid changes in genetics, however, can happen as when local populations are reduced to low numbers. Climate change, soil development, evolution, and human activities all provide a context for succession; sequences of species turnover that had occurred in one era may be impossible in the next.

Successional patterns reflect species accommodations to established environmental conditions and disturbance regimes. If the intensity, return interval, and area affected do not exceed limits imposed by rates of soil development, species longevity, and dispersal, even stand-replacing crown fires can be integrated into evolutionary and ecological systems (Pickett 1976, Odum 1969, Turner et al. 1993). This integration has occurred in fire-dependent systems such as northern coniferous forests (Wright and Heinselman 1973). New successional patterns, however, are established following novel, extreme (**catastrophic** or cusp) events (Jameson 1994). Introduction of new, nonnative species (e.g., domestic livestock, weeds, insects and pathogens) may so re-sort species relations and environmental conditions that whole new vegetation emerges (see Sprugel 1991 for several examples). Southwestern white pine is a minor or major seral species in many mixed conifer habitat types of the Southwest (Moir and Ludwig 1979). But southwestern white pine is susceptible to blister rust. This stem disease is lethal to seedlings and saplings and has recently become established in southern New Mexico (Hawksworth and Conklin 1990). In some areas, southwestern white pine could even be extirpated. The effect in the Southwest of eliminating this seral species on successional pathways is unknown; but in the northern Rockies the ecological consequences of blister rust has been significant (Monnig and Byler 1992).

## Succession and Ecosystem Trends

Ecosystem processes such as nutrient cycling are expected to respond with changes in the dominant vegetation of a site. Although it is quite evident that there are environmental and biotic differences between seral stages (if not, they wouldn't be recognized), there is a lack of agreement on which ecosystem trends are linked to succession and how they are linked. Odum (1969) categorizes ecosystem trends as community energetics, community structure, life history, nutrient cycling, selection pressure, and overall homeostasis. Some obvious and well-observed trends in the physical environment (especially light and moisture) result directly from changes in community structure as succession proceeds through the various physiognomic stages (Oliver 1981). Commonly observed trends are biomass accumulation, reduction of radiation below the canopy, and moderation of environmental extremes. Forest sites become more mesic as succession proceeds. Odum (1969) goes further in his contrast of young (early seral) and mature (later seral or climax) ecosystems. He suggests that production, growth, and quantity are associated with young systems and protection, stability, and quality are associated with mature systems. Observations of specific attributes such as ratios of production to respiration, species diversity, organism size, and nutrient conservation in actual ecosystems, however, do not always support the predictions (see Odum 1985). Even greater controversy arises from differences in explanations of the mechanisms responsible for observed trends. For example, DeAngelis and Waterhouse (1987) suggest that species stability is not fundamentally a property of ecological systems, but that an equilibrium state can emerge with extrapolation to sufficiently large spatial scales.

## Succession in the Southwest

Many disturbance events like fires and insect outbreaks have not been allowed to run their natural courses over the past century. Consequently, they have become less frequent but more severe. Suppression of natural disturbances like fires and insects and deliberate removal of some late seral communities through logging may have resulted in an artificial over abundance of mid-seral communities.

Johnson (1994) reports that the area of both aspen and ponderosa pine decreased on national forests in the Southwest by more than 425,000 acres between 1962 and 1986. Most of the land that had been occupied by these early seral communities became part of the mixed conifer forest through succession. While this vegetation was succeeding to a later sere, average stand age decreased as harvest removed older trees and encouraged regeneration. The result has been a more homogeneous forest that lacks stands in the youngest and oldest classes.

In 1987, only 7 percent of national forest timberlands in the Southwest were **nonstocked** or in seedling and sapling age classes (Conner et al. 1990, Van Hooser et al. 1993). Reynolds et al. (1992) estimate that approximately 20 percent of timberlands would need to be in these condition classes to provide all age classes, including old growth, on a balanced, sustained basis.

# RESULTANT CHANGES IN FOREST CONDITIONS

The changes in disturbance regimes and other forest processes listed previously have resulted in a transformation of forest conditions such as structure and composition. These changes in forest condition further contribute to changes in processes in a feedback cycle. Some of the structural changes that have been observed in Southwestern forests are listed below.

## Forest Overstory/Understory Relationships

Structural diversity in the forests of the Southwest has changed considerably, including understory plants. Heavy livestock grazing not only removed the fine fuels needed to carry a fire but shifted the competitive advantage from the herbaceous understory to tree seedlings. This increased tree density within the forest and allowed tree expansion into meadows. As the large ponderosa pine and Douglas-firs trees were harvested, they were replaced by numerous seedlings which were not thinned by fire as in the past. Expanding coniferous thickets suppressed understory plants. Over large areas, important components of structural diversity, namely meadows, open-canopy and old-growth forests, have been converted to pine and fir thickets (Moir and Fletcher 1996).

The relationship between overstory density and understory productivity has been documented in numerous studies. Covington and Moore[10] estimate the increase in overstory canopy density in the past century has reduced herbage production by 92 percent within some ponderosa pine stands.

Moore and Deiter (1992) report on the relation between **stand density index** and understory productivity in a ponderosa pine forest on the Kaibab Plateau. Productivity of grasses, sedges, forbs, and shrubs decreased with stand density index; the rate of decrease was steepest at stand density index values from 0–500 (Figure 5.6). These results support earlier

[10] *Unpublished report for Water Resources Operations, Salt River Project.*

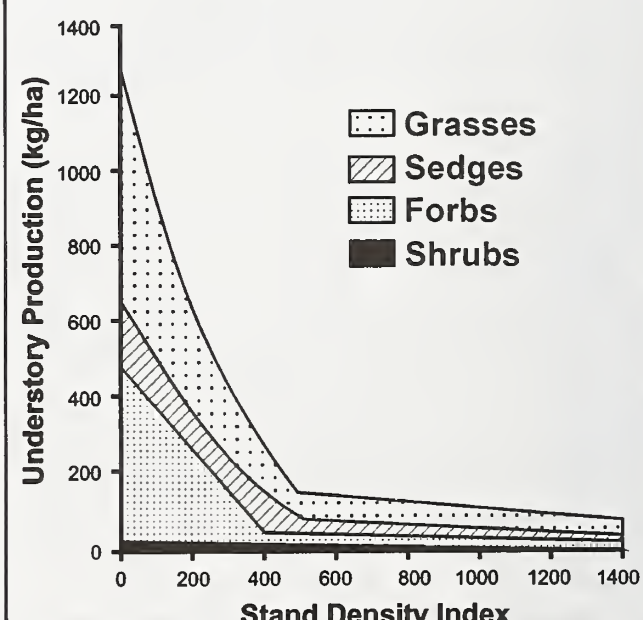


**Figure 5.6 Understory productivity of grasses, sedges, forbs, and shrubs by stand density index of ponderosa pine on the Kaibab Plateau, Arizona (redrawn from Moore and Dieter 1992).**

findings by Jameson (1967) for overstory–understory relations in ponderosa pine in northern Arizona and pinyon–juniper in northern and central Arizona. The understory within the ponderosa pine stands was 36 percent by weight Arizona fescue (*Festuca arizonica*) and 49 percent mountain muhly (*Muhlenbergia montana*). Productivity declined with increasing overstory basal area and with percent canopy cover; the decrease was steepest from 0 to 40 sq. ft. per acre (Figure 5.7) or 0 to 20 percent canopy cover (Figure 5.8). The understory within the pinyon–juniper stands was dominated by blue grama (*Bouteloua gracilis*) and broom snakeweed (*Gutierrezia sarothrae*). Productivity declined with percent canopy cover (Figure 5.9), but the decrease was less steep than in the ponderosa pine stands. Although these relations should apply generally throughout the Southwest, herbage production at any given forest density will vary from area to area depending on the site's capacity and history.

Variations in overstory–understory relations are due to differences in fire regime, grazing history, species composition, climate, and parent material. The decline in productivity displayed in Figures 5.6–5.9 may not have been as steep if these stands had been more frequently burned (especially, the ponderosa pine) and not as heavily grazed (both the ponderosa pine and pinyon–juniper). A variety of cool-season grasses are well adapted to the pinyon–juniper understory, and some species even increase in abundance as canopy cover increases. Clary and Morrison (1973) find that cool-season grasses such as mutton grass (*Poa fendleriana*), squirreltail (*Elymus elymoides*), Junegrass (*Koeleria macrantha*) and western wheatgrass (*Pascopyrum smithii*) were more abundant in northern New Mexico under the canopy of large alligator junipers than in open spaces. Pieper (1994) reports pinyon ricegrass (*Piptochaetum fimbriatum*) and New Mexico needlegrass (*Stipa neomexicana*) were positively related to canopy cover. During his 12-year study, end-of-season, herbaceous, standing crops varied from 200 to 1000 kg per ha; differences in July–August precipitation explained over 40 percent of the variation in crop levels. Jameson (1966) examines differences in the effect of cover by one-seed juniper on growth of blue grama at sites either derived from granite or from limestone. Canopy densities up to 13 percent on the granite site and up to 31 percent of the limestone site had either no effect or even a positive effect on blue grama productivity. These relatively low canopy densities may

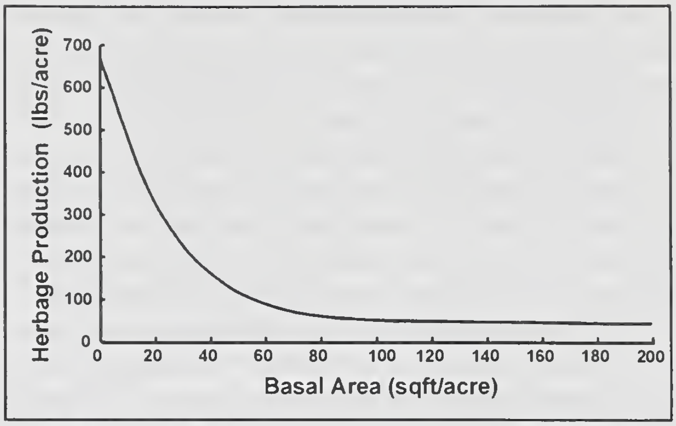


**Figure 5.7** Herbage production of Arizona fescue and mountain muhly in relation to basal area of ponderosa pine in northern Arizona (redrawn from Jameson 1967).

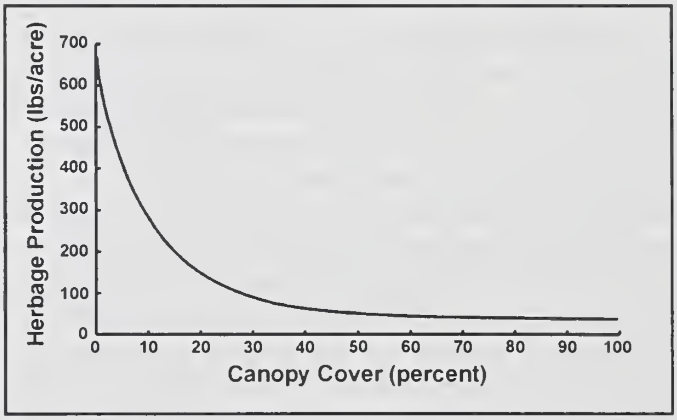


**Figure 5.8** Herbage production of Arizona fescue and mountain muhly in relation to canopy cover of ponderosa pine in northern Arizona, (redrawn from Jameson 1967).

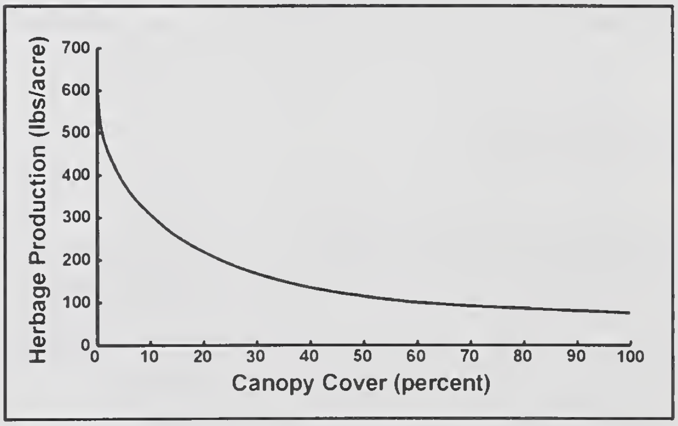


**Figure 5.9** Herbage production of blue grama and broom snakeweed in relation to canopy cover of pinyon and juniper in northern and central Arizona (redrawn from Jameson 1967).

have benefited the understory by reducing evapotranspiration or ameliorating temperature; higher tree densities may have impacted understory growth by shading or various belowground effects.

Although little is known of how belowground processes may have changed since the Territorial Period, mycorrhizae, nutrient cycling, and carbon cycling are fundamental ecosystem processes that strongly interact with both the overstory trees and the understory vegetation. Perry et al. (1989) describe the ecosystem relation between plants and soils, especially soil microbes, as a self-generating positive feedback system. A large share of the primary productivity of plants is allocated to roots and symbiotic fungi that form specialized root-fungus structures called mycorrhizae (Allen 1991, Brundrett 1991). Most plants and all conifers studied in natural ecosystems are mycorrhizal (Perry et al. 1989). Mycorrhizae increase plant nutrients and water and provide protection against some pathogens (Klopatek 1995). Mycorrhizae are important for seedling establishment and growth. Nutrient cycling, especially nitrogen which is essential for plant growth, depends on various soil microbes. Organic material in the soil affects its texture and water-holding capacity (Harvey et al. 1987). The breakdown and release of carbon in the soil is effected through shredding by arthropods and other macroorganisms, cellulose digestion by fungi, and additional decomposition by other microbes. Grazing affects these soil processes by reducing the carbohydrates available to mycorrhizae, the litter input to the soil, and the mulching effect of ground cover. Fire affects these processes by lethal temperatures and rapid mineralization. Both grazing and fire can lead to excessive soil erosion or leaching. As with various aboveground processes, the effects of disturbances and belowground responses vary by forest community.

## Oak Woodland

Harrington (1985) claims that summer burns repeated at frequent intervals reduces the density of Gambel oak. At least in the lower elevations, oak density has probably increased during the last century because of fuelwood harvesting and decreased frequency and severity of fire (McPherson 1992).

Studies in the oak woodlands of southeastern Arizona document a decrease in the number of trees, particularly large trees, an increase in mesquite and juniper in the lower elevations, and a decline in grasses, all of which are related, at least to some degree, to human factors (Bahre and Bradbury 1984, Hadley et al. 1991). Fuelwood harvesting in historic times was a major extractive activity. Over-grazing was also prevalent, and fire suppression in more recent times no doubt affected the composition of the oak woodlands (Propper 1992).

The normal result of increased tree density in forested ecosystems is reduced density and diversity of other plant species. In many woodland areas, the ability of understory grasses to control erosion is not offset by greater tree density. The result is increased surface erosion with permanent loss of productive capacity for the site. If allowed to progress, it may be impossible to replace the original plant community in less than geological time. If understory species become extinct, then the original community can never be replaced.

## Coniferous Woodland

Pieper and Lymberry (1983) describe changes to the coniferous woodlands:

> "Prior to widespread settlement of the Southwest, pinyon–juniper stands were more open and were confined largely to the rocky ridges or more level sites with shallow soils—tree densities have increased with subsequent invasion into adjacent grasslands."

The pinyon–juniper woodlands may not have been as confined to rocky shallow sites as this description suggests. The General Ecosystem Survey identifies vast areas of established coniferous woodlands on deep, productive soil of level sites (i.e., GES Map Unit 130). But the GES data also support the view that the extent of coniferous woodlands has increased. Pieper and Lymberry (1983) attribute this increase to lack of periodic fires, increased spread of seed by livestock, overgrazing and resultant reduction in competition by grasses, and a shift in climate favoring the woody species. These factors have accelerated succession to woody species, especially during wet years favorable for regeneration of shade-tolerant trees (Johnsen 1962). Heavy grazing led to a reduction in the numbers and intensities of fire that has resulted in a significant expansion of junipers (Wright 1990). Since the historic period, coniferous woodlands have generally become more dense and extensive, primarily by expansion into shrub–steppe and grasslands. As in the oak woodlands, coniferous woodlands have experienced reduced diversity of understory species, increased erosion, reduced productivity, and possible permanent changes in dependent plant and animal communities. Invasion of other plant communities by woodland species reduces biodiversity on a landscape scale.

In some areas, coniferous woodlands have been manually converted to grasslands. From 1960 to about 1970, there was a widespread but controversial effort to convert woodlands to grasslands. de Buys (1985) describes an incident near Pecos, New Mexico where the Forest Service cleared 13,000 acres of woodland and reseeded them to grasses. This action was warmly received by grazing permittees, but upset village residents who depended on the area for fuelwood. These reactions typify the contrast in attitudes over woodlands—some people value woodlands for aesthetic or utilitarian reasons whereas others view woodlands as a mere impediment to livestock grazing (Lanner 1977).

Grazing has affected cryptogamic soil crust present in some woodland areas. Cryptogamic soil crust has a stabilizing influence on the soil surface (Bailey et al. 1973, Anantani and Marthe 1974a, 1974b). The increased porosity typical of crusted soils improves infiltration of rainwater, thus reducing runoff and subsequent erosion (Booth 1941, Loope and Gifford 1972). Additional benefits are increased fixation of atmospheric nitrogen and improved soil water and nutrient levels (Durrell and Shields 1961). Trampling of cryptogamic soil crust significantly disrupts this process. Research by St. Clair et al. (1984) indicates that an intact or recovered crust enhances seedling development, regardless of the crust composition.

## Ponderosa Pine

Striking changes have occurred in the ponderosa pine forests of the Southwest. Over large areas, the open structure of historic forests has been replaced by dense thickets of sapling and pole stands (Harrington and Sackett 1990). A disturbance regime of frequent, low-intensity fires has been replaced with one of stand-replacing, high-intensity fires.

These changes had their beginning in the intensive livestock grazing of the late 19th century (Faulk 1970). Much of the herbaceous vegetation could not survive the grazing pressure, and its coverage declined drastically. Because of a decrease in fine fuels, this vegetation decline led to a reduction in fire spread that preceded organized fire suppression by one or two decades (Touchan et al. 1996). Forestry practices in the early 1900s further reduced the spread of fires. Because virtually all Southwestern fire history studies (Weaver 1951, Dieterich 1980, Swetnam 1990, Allen 1989, Savage and Swetnam 1990) report a similar pattern, a reduction in fire frequency of the early 20th century was probably common throughout the ponderosa pine forests of the Southwest.

In addition to a reduction in fires, ponderosa pine forests also experienced increased logging and reduced growth of herbaceous understory. With less herbaceous competition, improved soil conditions for seed germination, and better seedling survival, ponderosa pine regeneration, particularly in wet years, increased dramatically (Cooper 1960). Before, densities had been 3 to 56 trees per acre (Covington and Moore 1992); by 1986 ponderosa pine density on National Forest lands was 294 trees per acre (Johnson 1994). Many of these trees occur as stagnant thickets of saplings and poles; fuels are at unprecedented levels (Biswell et al. 1973).

An increase in stand density alone does not describe the changes to the forest structure of Southwestern ponderosa pine. Changes in size class distribution and numbers of large, yellow pine are also important but controversial. Although different areas were surveyed or different size classes were used, there are a number of inventories that can be used to examine changes in forest size structure (Figure 5.10). Woolsey (1911) reports the results of inventories on three national forests, and Lang and Stewart[11] report a inventory of what is now the North Kaibab Ranger District. These inventories can be compared with data of Conner et al. (1990) and Van Hooser et al. (1993) as re-compiled by Woudenberg (Intermountain Research Station, personal communication).

Early surveys by Woolsey (1911) and by Lang and Stewart and recent surveys by Conner et al. (1990) and Van Hooser et al. (1993) include relatively large acreages of Southwestern ponderosa pine and use similar size classes. The Woolsey (1911) survey represents 1,888 acres of well-watered, rolling malpais flats with good stocking (Coconino National Forest), 5,920 acres on southeastern exposure, with dry soil, volcanic cinder, and light stocking (Tusayan Forest), and 128 acres on the Prescott National Forest.

*[11] Unpublished report titled Reconnaissance of the Kaibab National Forest, unpublished survey report circa 1910 on file Williams, AZ: U.S. Department of Agriculture, Forest Service, Kaibab National Forest.*

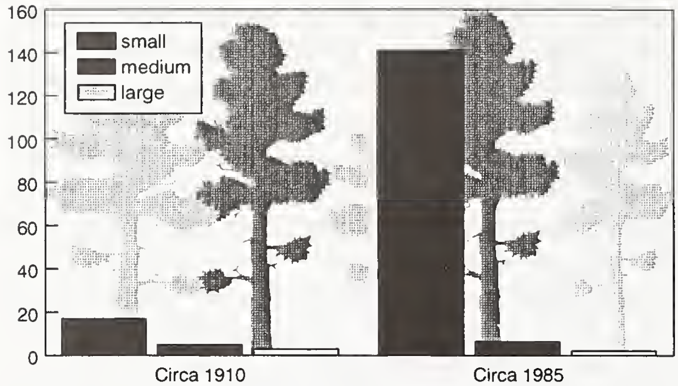


**Figure 5.10 Change in size-class distribution of ponderosa pine 1910 to 1985. The number of trees per acre are estimated from several forest inventories circa 1910 (Lang and Stewart unpublished on North Kaibab Plateau and Woolsey 1911 in northern Arizona) and circa 1985 (Conner et al. 1990 in Arizona and Van Hooser et. al 1993 in New Mexico). Size classes for the early inventories are small, 4 to 18 inches dbh; medium, 18 to 24 inches dbh; and large, greater than 24 inches dbh. Size classes for the later inventories are small, 6 to 18 inches dbh; medium, 18 to 23 inches dbh; and large, greater than 23 inches dbh.**

Lang and Stewart surveyed eight acres per quarter section across the North Kaibab Ranger District. These early surveys grouped trees 4 to 18 inches in a small-diameter class, trees 18 to 24 inches in the medium-diameter class, and trees over 24 inches in the large-diameter class. Conner et al. (1990) reports inventory totals for all forested lands in Arizona (survey 1985), and Van Hooser et al. (1993) reports inventory totals for New Mexico (survey 1986-1987). These recent surveys grouped trees 6 to 18 inches in the small class, 18 to 23 inches in the medium class, and trees over 23 inches in the large class.

Changes in the stand structure of Southwestern ponderosa pine from the early 1900s to the 1980s are illustrated by size-class distributions (Figure 5.10) using data from Woolsey (1911), Lang and Stewart, Conner et al. (1990), and Van Hooser et al. (1993). The most obvious change has been the increase in small-diameter trees (less than 18 inches dbh) from 17 trees per acre to 140 trees per acre. The number of medium-diameter trees (18 to 23 or 24 inches dbh) increased slightly from 5 to 6 trees per acre. The number of large-diameter trees (over 23 or 24 inches), however, decreased slightly from 3 to 2 trees per acre. Because of disparities in survey area and methods, no statistical significance can be placed on these differences, but they probably well reflect actual changes from a forest dominated by few but large trees to a forest of many small and few large trees.

Probably the largest effect on forest health in Southwestern ponderosa pine is due to the increase in the density of the trees. This effect is expressed in several ways:

1. Increased tree density reduces the abundance and diversity of understory plants.
2. Since most of the increase is in smaller trees, there is an increase in ladder fuels, so that crown fires, once rare in ponderosa pine, are now common.
3. Increased tree density increases susceptibility to bark beetles.
4. Dense, multi-storied stands provide suitable conditions for rapid spread and intensification of dwarf mistletoe.
5. Increased density results in lower water yields, which has a negative impact on riparian areas.

In addition to increased density, ponderosa pine forests have tended to become more uniform, with the loss of structural and compositional diversity (see Chapter 5). We do not have good inventories of the amount of land in old-growth condition, either prior to European settlement or now. However, many people believe that there is less old growth now than there was before logging began. The lack of a commonly accepted definition of old growth and a lack of information on pre-settlement conditions makes this difficult to verify. If true, it may indicate that in recent times there have been too many minor disturbances and too few major disturbances. A major disturbance could move an area into a condition where the trees would be both young and would consist of early seral species. Minor disturbances like selective harvest or thinning could result in the loss of only certain species or certain age classes. They could move an area from late seral to a middle seral condition or from a stand of old trees to a stand of middle-aged trees but fail to take it all the way back to an early seral condition or a very young age. The lack of early and late seral conditions and young and old stands could cause reduced populations of plants and animals that depend on these conditions, thereby reducing the biodiversity of the forest.

All of this indicates that attempts by managers to reduce disturbances like low-intensity fires and periodic insect outbreaks are at the heart of the unhealthy conditions existing in ponderosa pine forests today. The future health of these forests demands more disturbance, not less. However, these disturbances must reflect the historic variability in terms of frequency, intensity, and size to insure that the resulting forest structure and composition are sustainable.

### Mixed Conifer

Although we do not have the detailed early inventories for mixed conifer forests that we have for ponderosa pine forests, it is reasonable to assume that many of the same types of changes have also occurred there. Whereas fires previously occurred at intervals of 5 to 25 years (Table 4.1), they now occur at much longer intervals and with much higher intensity. As in ponderosa pine, increased overall density and increased numbers of small trees contribute to the frequency of crown fires and the susceptibility to bark beetle attacks. An additional change in mixed conifer stands, however, is a trend toward larger numbers of late seral species such as white fir and Douglas-fir and reduced numbers of early seral species such as ponderosa pine and aspen.

Increased tree densities and multi-storied stands of late seral species are very favorable conditions for attack by the western spruce budworm. Increasing the proportion of Douglas-fir in a stand also makes it easier for Douglas-fir dwarf mistletoe to spread and intensify. Loss of ponderosa pine and aspen from mixed conifer stands further reduces biodiversity. Increased overall density will also reduce the abundance and diversity of understory plants.

The 1962 and 1986 forest inventories for the Southwest indicate the extent of meadows within the mixed conifer forest. In some areas, there is evidence that these open montane grasslands are shrinking, with some small openings disappearing altogether. In the Jemez Mountains of northern New Mexico, for instance, more than 55 percent of the high elevation grasslands have been lost since the early 1900s. This loss is attributed to conifer encroachment caused by overgrazing and the removal of fire (Allen 1989). Over 40 percent of the species found in meadows are not found in adjacent mixed-conifer forests. The fragmentation of meadow habitats into smaller, more isolated parcels limits the ability of the ecosystem to support historic wildlife populations.

### Spruce–Fir

The spruce–fir forest has always been an area of both rare but high-intensity disturbances and frequent patch-scale disturbances. Grissino-Mayer et al. (1995) reports that a severe fire every 300 to 400 years returns the spruce–fir of the Pinaleno Mountains to an early successional stage. The spruce beetle, high winds, and root disease can also rarely cause stand-replacing disturbances or patch-scale openings in the spruce–fir forest.

Due to the low product value and the difficulty of building roads, relatively little logging was done before 1950 in spruce–fir forests (Alexander and Edminster 1980). Because these forests were neither roaded nor cut, large portions were designated as Wildernesses. Spruce forests outside of reserved areas, however, have been extensively logged over the past 50 years. Because the natural disturbance regime of spruce–fir forests includes infrequent but high-intensity events like windthrow, fire, and spruce beetle epidemics, the current stand age-class structure of the spruce forest is probably not outside the historic norm.

### Aspen

Johnson (1994) reports a 46 percent decline in aspen forest cover during the period from 1962 to 1986. This decline represents a substantial reduction in landscape biodiversity. The enormous aspen stands reported by Pearson (1931) no longer exist, and the number of smaller ones has decreased. Aspen is an early seral species that requires high-intensity disturbances such as stand-replacing fires or clearcut logging for successful regeneration. Because elk, deer, and livestock heavily browse young aspen sprouts and can destroy entire areas of regeneration, restoration of aspen is difficult. Some forests (e.g., Coconino and Apache–Sitgreaves) have resorted to installing very expensive fences capable of excluding not only cattle, but also deer and elk. If large fires were to occur in the mixed conifer forest, so much of the area may regenerate to aspen that animal damage would be widely dispersed and aspen could re-establish. This has not yet been demonstrated. Once established, aspen stands can usually persist for about 100 years before they deteriorate and are replaced by conifers.

Although aspen is little used in the Southwest for timber (except locally for house logs), aspen is an important ecological feature and recreation attraction. Aspen groves provide important foraging, nesting, breeding, and resting sites for over 200 wildlife species. Fall coloration by aspen draws numerous visitors to the Southwest, especially northern New Mexico. If current trends of reducing acreage of aspen continue, these values would be lost.

### Riparian Wetlands

In alpine riparian systems, including montane cienegas, the process of trapping sediments moving over channel bottoms by native aquatic vegetation is important to their long-term stability. Under impacts such as livestock grazing starting in the late 1800s, native ungulate grazing, and the reduction of aquatic plants, high-elevation stream systems initiated a process of degradation and stream-channel down cutting. Introduced graminoids such as *Poa, Agropyron,* and *Dactylis* are able to invade riparian areas. But they are less able to withstand the various impacts of grazing, and their root systems are less able to prevent channel aggradation (Neary and Medina 1995).

The floodplains–plains riparian systems of the Southwest have suffered more from human activities than other riparian associations (see Chpater 5). The floodplains portion is typically found on older, meandering river systems with extensive flats. One manifestation of human activity is the explosion of exotic shrubby species such as Russian-olive in the northern river sections and saltcedar in the southern parts of the region and northwestern New Mexico. The gallery forests that covered the floodplains riparian systems were composed of large trees and were often close to human settlements. Trees were initially cut for fuel and shelter. Riparian trees were also cut to clear land for agriculture and settlement. The natural resiliency of riparian vegetation might have eventually resulted in the restoration of the former forests, if it had not been for the impoundment of the streams and rivers.

The hydrology of dammed rivers was altered in ways that thwarted some of the reproductive mechanisms of native riparian species. Wells and drains dropped water tables and reduced the number and extent of **phreatophytic** habitats. Not only were flow rates below dams reduced, but annual flooding of benches and terraces bordering channels was eliminated. This drastically curtailed the major reproductive mechanisms for cottonwoods. The decline in the number of native trees and the altered available water regime on rivers and streams, coupled with livestock grazing, have eliminated some wet meadows and set the stage for the establishment of exotics such as Siberian elm (*Ulmus pumila*), Russian-olive, and saltcedar (Dick-Peddie 1993). Costs of eradication, if desirable, are high. For example, removal of all the saltcedar along the Lower Colorado River and restoration of native vegetation have been estimated at between $45 and $450 million (USDI Bureau of Reclamation 1992).

These impacts and others, such as the removal of beavers from many waterways, have caused an overall deterioration of riparian ecosystems. Those wildlife species dependent on riparian ecosystems that are currently at reduced population levels are at risk for further declines in population as **threatened**, **endangered**, or **sensitive species** (**TES**). The influence of brown-headed cowbird (*Molothrus ater*) parasitism to many small songbirds continues to be pervasive due to readily detectable nest sites caused by the lack of dense riparian vegetation. Insectivorous bird species that prefer slow-moving insect-rich boggy areas will continue to decline due to the lack of vegetation and beaver activity. The majority of species currently on the Regional Forester's Sensitive Species list for the Southwestern Region are riparian-dependent species or species which thrive in healthy riparian ecosystems.

## WILDLIFE POPULATION DYNAMICS

In the past 150 years, significant changes have occurred to wildlife populations of the West. In general, some species have been extirpated, some have increased in abundance, and some new species have been introduced. Despite the lack of data, there is consensus that as resource management intensified, ecosystems were simplified, habitats were fragmented, and animal populations declined (Harris 1984).

Virtually all of the game animals are at significantly increased levels compared to the 1890s. Wildlife population estimates are difficult to obtain and are seasonally dependent. Populations in the spring, after the peak of reproduction and prior to juvenile mortality, can be several times greater than populations after hunting and winter mortality. Wildlife estimates for Arizona are estimates from the Arizona Game and Fish Department for post-hunt adults; estimates for New Mexico are from the New Mexico Department of Game and Fish. Since populations fluctuate yearly with variations from site to site, population estimates at this broad scale should be used in the context of understanding overall trends through time, not site-specific analysis.

Large predators were aggressively persecuted until as recently as 1960. Gray wolves (*Canis lupus*), mountain lions, and grizzly bears (*Ursus arctos*) were largely extirpated from most Western states. Mountain lion populations have rebounded in most Western states since 1970. Black bears and mountain lions are managed through regulated hunts in New Mexico and Arizona. Black bear numbers were estimated to be 770 in New Mexico in 1926 and increased under hunting regulation to about 3,000 by the early 1960s (Ames 1967). Information from ongoing research indicates that the current New Mexico population may be 4,000 to 6,000 animals. The black bear population in Arizona has apparently remained stable over the last 10 years and is estimated at about 2,500 animals.

Thomas and Toweill (1982) report on the history of elk populations. Unregulated hunting, including market hunting, reduced elk populations to low numbers by the 1890s; a few years later, elk were extirpated from Arizona. Tragically, Merriam's elk (*Cervus elphus merriami*), a subspecies found in southern New Mexico and Arizona, became extinct by 1900. Rocky Mountain elk were extirpated from northern New Mexico around 1909. Reintroduction efforts began in 1910 and continued through 1966 (Gates 1967). After 1900, following a four-decade period of low or no legal hunting, elk populations began to recover. Today, elk numbers in some areas appear higher than during any period in recorded history (Irwin et al. 1993). The 1994 estimate of elk in Arizona was 29,000 adults. In New Mexico, elk numbers were estimated to be 712 in 1926 and grew to about 11,000 to 12,000 in the early 1960s (Ames 1967). The current elk population in New Mexico is estimated at 30,000 to 50,000 adults.

Deer populations are more variable in number. Irruptions occur periodically in which large populations are observed that subsequently crash. Causes for these irruptions were varied and probably interdependent (Caughley 1976, Pengelly 1976, Mitchell and Freeman 1993). Causes include such factors as predator control, protection from hunting, drought, disruptions of the natural fire regime, logging, and competition with cattle. In Arizona, from extreme low numbers in the 1890s, deer peaked about 1960. After an extended drought in the 1970s, they peaked again in the mid-1980s. The current population is again at the relatively low level of the 1970s. 1994 Arizona population estimates for mule deer and white-tailed deer (*Odocoileus virginianus*) are 120,000 and 82,000 respectively. In New Mexico, mule deer reached a low population around 1926 at an estimated 41,000 animals. Numbers increased until about 1960 at an estimated 318,000 animals (Ames 1967). Mule deer populations fluctuate greatly due to the influence of weather on reproduction and survival. Post-hunt population numbers for all age classes have probably fluctuated between 235,000 to 300,000 animals during the past 10 years.

In the late 1890s, big game seasons were closed for bighorn sheep and pronghorn in Arizona. At this time, mountain bighorn sheep were estimated at no more than 1,500 animals in Arizona. By the early 1900s, mountain bighorn sheep were extirpated from New Mexico (Sands 1967). Restoration of bighorn sheep began in 1932 in New Mexico and continues to the present day. Currently, five populations exist totaling an estimated 570 animals, with the majority located in the Pecos Wilderness. Desert bighorn sheep in the San Andres and Big Hatchet Mountains in New Mexico reached a low in about 1955. Transplants have been made to the Peloncillo, Hatchet, and Ladrone Mountains between 1979 and 1993 from the Red Rock captive population. Total numbers in 1994 are estimated at 360 animals. The 1994 estimate of bighorn sheep in Arizona is 6,500—about 6,000 desert bighorn sheep and about 500 mountain bighorn sheep.

In the Southwest, pronghorn numbers reached a low in the early 1900s. At that time, there were an estimated 1,200 animals in New Mexico (Larsen 1967). The transplant program begun in 1937 has been responsible for reintroducing pronghorn to most suitable habitats in New Mexico. The 1993 New Mexico population estimate is 36,000 animals (Gleadle 1994), and the 1994 Arizona estimate is 7,800. Pronghorn populations are subject to great fluctuations due to changes in habitat quality.

Javelina in New Mexico received protection as a game species in 1937 (Donaldson 1967). Numbers were then estimated to be 400 and 3,500 by 1964 (Ames 1967). It has been noted that their distribution has been expanding through natural dispersal to the San Andres and Guadalupe Mountains. Current numbers are unknown but may be increasing. The Arizona estimate for javelina in 1994 is 38,000 animals.

Wild turkey populations can fluctuate widely from year to year. In New Mexico, turkey numbers reached a low by about 1926 and were estimated to be 21,000 statewide. The population was estimated to be about 25,000 in 1964. No current statewide estimate has been made. In Arizona, there are currently between 30,000 and 40,000 turkeys.

Another influence that altered Southwestern ecosystems was the removal of beaver by aggressive fur trapping. Tens of thousands of beaver were removed from riparian areas. Their removal encouraged channelization and reduced the hydrologic effect of pooling. The loss of beaver affected native fish such as the Apache trout (*Salmo apache*) and Rio Grande cutthroat trout (*Salmo clarki*), and birds dependent upon insect-rich boggy conditions. It also narrowed the riparian corridor due to decreased water infiltration. In many areas of the Southwest, beaver have not returned to many historic waterways.

Numerous activities of management and resource use have had detrimental effects on populations of native fish. Poisoning "undesirable" fish and stocking popular game species such as the rainbow trout (*Salmo garidneri*), reduced native populations and introduced competitors and predators. Mining, timber harvesting, and livestock grazing have all affected water quality and riparian habitat. In the warm and sunny Southwest, riparian vegetation is especially important for cooling and shading forest streams. The native fish most sensitive to these changes include the Apache trout, Gila trout (*Salmo gilae*), Little Colorado spinedace (*Lepidemeda vittata*), spikedace (*Meda fulgida*), loach minnow (*Tiaroga cobitis*), and Sonora chub (*Gila ditaena*).

Each forest type and its respective successional stages have specific wildlife communities associated with them. As cover type and/or successional stages change, there are corresponding changes in the composition of wildlife communities. The BISON-M habitat relationships database was queried to analyze the numbers of birds and mammals in different cover types and successional stages to evaluate effects of vegetation trends. Seventy-three percent of birds and mammals found in grasslands are not found in pinyon–juniper woodlands. Therefore, increasing acreages in pinyon–juniper woodland will negatively affect some grassland species. Likewise, shifts from ponderosa pine to mixed conifer also affect wildlife composition.

The rapid change of aspen to mixed conifer is one of the most significant concerns to wildlife management. Although both communities have many species in common, there is a distinct suite of birds and mammals that occur only in aspen. In addition, aspen provides a broadleaf component that is important to certain invertebrates, such as the western tiger swallowtail (*Papilio rutulus*) and red-spotted purple (*Basilarchia astyanax*) butterflies.

The size and abundance of meadows is declining in the Southwest as conifers encroach. Forty-six percent of the species found in meadows are not found in mixed conifer forests. The fragmentation of meadows limits the habitat's ability to support wildlife species that require large meadows.

## AIR QUALITY

In Arizona the number of areas that do not meet National Ambient Air Quality Standards has increased over time, while by comparison air quality in New Mexico remains more pristine. However, efforts to maintain good air quality in New Mexico have increased, as demonstrated by mandatory no-burn policies during air temperature inversions that affect Albuquerque. Most Forest Service resource inventory and monitoring for air pollution effects has focused on establishing current conditions. Few long-trend analyses have been conducted. However, the National Acid Precipitation Assessment Program and the Interagency Monitoring of Protected Visual Environments (IMPROVE) network have summarized long-term data for western states.

Terrestrial and aquatic ecosystems and visibility have been affected by atmospheric pollutants. Sensitivity to acidic deposition is a function of geologic characteristics of the watershed, soil and vegetation type, hydrologic characteristics, chemical and biological characteristics of the ecosystem, and precipitation volume. Mercury, which could be from the atmosphere, and other trace metals have bio-accumulated in fish tissue, and health advisories have been issued in some areas. A loss of acid-neutralizing capacity due to high sulfur or nitrogen deposition has been documented in the Southwest. Episodic acidification has been detected at some high elevation lakes or streams. Paleobotanical reconstructions infer changes in lake species that may relate to changes in lake chemistry caused by atmospheric pollutants. These changes indicate a shift to more acid-tolerant species may be occurring in some high elevation lakes in New Mexico. Ozone, which is toxic to plants, is also a concern, particularly near large urban areas where combustion from various sources generates ozone precursors.

Sulfate aerosols from all sources (including power plants and copper smelters) and other fine particles and gases in the atmosphere impair scenic vistas in the Southwest. For example, data from the Interagency Monitoring of Protected Visual Environments network show that in autumn sulfur concentrations have steadily increased since 1980 at Grand Canyon National Park. The National Academy of Sciences (1993) state that "the average visual range in most of the western United States...is about one-half to two-thirds of the natural visual range that would exist in the absence of air pollution."

# CHAPTER 6: A SUMMARY OF CURRENT ECOSYSTEM CONDITIONS

"...a society and its biophysical environment are interactive, interadaptive, and interdependent in a single biosocial system of constant mutual adjustment."

R. W. Behan (1995)

This documents the current status of selected ecosystem indicators for forests and woodlands of the Southwest. The integration and interpretation of these indicators from the conditions described in chapters 3 to 5 provide both a summary for specific biotic communities and a statement of professional expertise and judgement of the team. Ecosystem conditions in this chapter are defined by the following questions:

1. Is adequate provision made for the conservation of biological diversity? The maintenance of biodiversity includes, at a broad scale, maintaining the composition and arrangement of species and ecosystems across the landscape and, at a lower level of organization, maintaining the diversity of gene pools within a species. Diversity is important in forested ecosystems because a loss of species is associated with an increased potential for species extinction or genetic loss of species with known or unforeseen ecological or societal value. Also, diverse ecosystems may be less susceptible to devastation by disturbance events.

2. Is ecosystem integrity and resilience maintained in the long term? These are respectively defined as the ability of the ecosystem: (a) to maintain vital ecological processes, such as energy flows, nutrient cycling, hydrologic cycling, soil development, plant community succession, animal population movements (i.e., migration), and unimpaired flow of genetic material at rates within the range of historic variability and (b) to recover biotic integrity following disturbance.

3. Are human needs for ecosystem resource use and landscape occupancy being adequately accommodated?

## WOODLANDS

### Biological Diversity

- A decreased diversity in grasses and forbs has resulted from less frequent burning than the historic fire regime.
- Herbivore use is above historic levels (prior to Territorial Period), resulting in decreased biotic and genetic diversity in native species.
- Past land disturbances have permitted increases in introduction and establishment of exotic species.

### Integrity and Resilience

- Soil erosion today is greater than in the past, resulting in decreased upland site productivity.
- Soil infiltration rates are below historic levels, resulting in greater overland flows, higher peak flows, reduced length of base flows in intermittent streams, and more confinement of channels.
- Some wildlife populations such as pronghorn have been isolated because of the construction of major highways.
- Culling of dying, standing dead, and downed pinyon and juniper trees through fuelwood gathering and **salvage** operations has reduced available snags and downed logs needed by many species of wildlife (e.g., insects, woodpeckers, bats, nuthatches, titmice, small rodents, and many reptiles). Opportunities are also lost for other benefits, such as the release of nutrients to the soil and increased plant growth adjacent to these structures.
- Stock tanks and ponds provide for increased habitat for species such as woodpeckers, frogs, elk, bats,

and other animals. These waters not only provide water for wildlife, but also attract insects, a source of food, and help disperse populations of wildlife.

### Human Needs and Uses

- Coniferous woodlands have changed from a visually diverse mosaic of tree-covered patches and corridors to a matrix of trees with more homogeneous tree cover and reduced overall scenic diversity and quality.
- Roads and utility corridors have changed the appearance of the landscape by adding foreign line elements that span wide areas.
- Past attempts at improving grazing conditions through chaining and pushing resulted in some large, geometric, linear, unnatural-looking patterns on the landscape.
- Controversies resulting from resource allocations between threatened species and traditional community uses, such as firewood gathering, have resulted in disputes between cultures.
- Woodlands are especially rich in heritage sites which have been susceptible to damage from human activities and natural processes such as erosion.

## PONDEROSA PINE

### Biological Diversity

- Because of changes in fire regime and forest management, there have been significant changes in the diversity of vegetation and wildlife. Many well-spaced groups of large yellow-bark ponderosa pine have been replaced with closed thickets of small, blackjack ponderosa pine or with mesic mixed conifer species.
- These changes have been accompanied by decreased diversity of grasses, forbs, and shrubs and by increased levels of surface organic material.
- Although wildlife species (some small mammals) that benefit from increases in mixed conifer or surface litter are more abundant, many other species dependent on open stands and large trees, and especially on large snags (cavity-dwelling birds and mammals), are found in fewer areas.
- Overall, the loss of large ponderosa pine trees has resulted in a reduction of vegetation and wildlife diversity.

### Integrity and Resilience

- Reductions in low-intensity fires, changes in species composition, and increases in stand density have altered both physical and biotic processes in ponderosa pine forests.
- Mortality of large trees by dwarf mistletoe, root disease fungi, bark beetles, and wildfire has replaced the understory thinning action of low-intensity ground fires as the principal forest disturbance.
- In general, the scale at which tree death and regeneration occurs has been altered from that of the rare loss of mature individuals (appearing as a constant, uniform change) to more common destruction of groups of trees (appearing as a more variable or chaotic change).
- Impacts from grazing and browsing of livestock and wildlife have resulted in decreased watershed cover and riparian stability in some areas.

### Human Needs and Uses

- Ponderosa pine forests have changed from a grass matrix with individuals, clumps, and stringers of various-sized trees (many large), to stands of mostly smaller trees with only an occasional grassy opening. Large trees are no longer found in well-spaced, open groves, but primarily as individuals, surrounded by smaller trees. The visual depth of forest landscapes has decreased due to these changes.
- Increased road densities have resulted in more visual opportunities, but also more visually displeasing road scars.
- Tree decline and mortality due to increased dwarf mistletoe infestations have negatively affected aesthetic qualities at recreation sites and within visual corridors.
- Increased dwarf mistletoe infestations have had a negative effect on timber production.
- Mortality of trees from pine bark beetle outbreaks has resulted in lost opportunities for timber production in the Sacramento Mountains. Outbreaks have occurred in dense stands of ponderosa pine primarily affecting trees of low-vigor, i.e., highly-stressed trees.
- Competition for forage and water between cattle and elk has created controversy over appropriate resource use.
- Controversy over resource allocations between threatened species and timber harvesting has

resulted in reduced viability for forest-dependent industries and increased demands for protection.
- Urban development in forested ecosystems has increased risks related to fire.
- Sulfate aerosols and other fine particles and gases in the atmosphere have impaired scenic vistas.
- Scenic and recreation values and expectations are often in conflict with extractive uses and timber management activities.

## MIXED CONIFER

### Biological Diversity

- The increase in mixed conifer acreage is likely to have slightly increased the diversity of vegetation types and possibly the diversity of wildlife species in some areas.
- With the decline of the aspen component in the mixed conifer, a broadleaf component that is important to some invertebrates such as the western tiger swallowtail and red-spotted purple butterflies is reduced.
- Populations of some bird species have increased due to increased spruce budworm infestations.
- Habitat for cavity-nesting birds has increased following spruce budworm infestations.

### Integrity and Resilience

- Due to widespread harvests and fire suppression, younger, multi-storied stands composed of more shade-tolerant trees are more common and more susceptible to western spruce budworm attacks. Sustained heavy defoliation by budworm has resulted in decreased growth, tree deformity, top killing and death. Stand level effects include changes in stand structure, reduction of understory, and a composition shift toward nonhost or less susceptible species.
- Spruce budworm infestations have decreased thermal cover and forage for wildlife but sometimes have increased water yield.
- Forest openings are fewer and smaller than in the past, resulting in reduced snow accumulation and faster spring snow-melt.
- The risks of acidification of high-elevation lakes have increased due to high sulfur or nitrogen deposition. Ozone toxicity to plants, particularly near urban areas, is a concern.

### Human Needs and Uses

- The visual diversity in the mixed conifer forests has decreased due to reduced regeneration of aspen stands. Seasonal color and textural contrasts between aspen and conifer have been reduced.
- Due to western spruce budworm infestations, visual quality and recreation use has been affected. Heavy defoliation, discoloration, top-killing, and tree mortality has reduced the visual quality of scenic corridors and heavily used recreation areas. In addition, the presence of large numbers of larvae has been a nuisance in campgrounds, picnic sites, and summer home areas.
- Sulfate aerosols and other fine particles and gases in the atmosphere have impaired scenic vistas.

## SPRUCE–FIR

### Biological Diversity, Integrity, and Resilience

- Relative to other vegetation communities, little change has occurred in these communities.
- The risks of acidification of high elevation lakes have increased due to high sulfur or nitrogen deposition.
- Ozone toxicity to plants, particularly near urban areas, is a concern.

### Human Needs and Uses

- Installations, such as radio towers, microwave facilities, and ski lifts, are the most notable visual changes to the spruce–fir and alpine meadow visual characteristics.
- Sulfate aerosols and other fine particles and gases in the atmosphere have impaired scenic vistas.
- Mountain peaks hold special cultural and religious value for many Southwestern Indian tribes giving rise to conflicts between traditional uses and other uses and development.

## ASPEN

### Biological Diversity

- There has been a 46 percent decline in the aspen cover type between 1962 and 1986, representing a loss of biodiversity at the landscape level.

### Integrity and Resilience

- Aspen regeneration has declined due to continued elk browsing of aspen sprouts, resulting in the death of the sucker root system.
- With the loss of the aspen component in the mixed conifer, we are losing a broadleaf component that is important to some invertebrates such as the western tiger swallowtail and red-spotted purple butterflies.

### Human Needs and Uses

- People are concerned about the loss of aspen as they are valued for their scenic beauty. They are also excellent sites for viewing wildlife and wildflowers.
- In many of the mountain towns and villages of northern New Mexico and Arizona, homes are still heated with aspen.
- Many rural people continue to depend on the sale of aspen wood products for part of their livelihoods.

## MONTANE RIPARIAN WETLANDS

### Biological Diversity

- Grazing and browsing in riparian areas have resulted in decreased diversity and cover in riparian vegetation.
- The number of impoundments and diversions and the level of grazing is greater than in the past, resulting in increases in the number and extent of exotic species in riparian areas.

### Integrity and Resilience

- Riparian corridors have been interrupted due to grazing and agricultural practices, resulting in decreased wildlife movement corridors, increased water temperatures, and decreased transport of organic materials.
- Disturbance due to flooding has been reduced below historic levels, resulting in decreased potentials for regeneration and reduced biomass production from native species. Channel stability has also changed due to reduced vegetative cover and changes in sediment transport.
- The risks of acidification of high elevation lakes have increased due to high sulfur or nitrogen deposition. Ozone toxicity to plants, particularly near urban areas, is a concern.

### Human Needs and Uses

- Riparian uses such as grazing, recreation, and agriculture frequently result in water quality not meeting standards for designated beneficial uses.
- Grazing and browsing in riparian areas has had a negative effect on scenic qualities and recreation experiences in some areas.
- Increasing competition for scarce water resources has resulted in conflicts between traditional uses, such as community acequias, and other uses and developments.

## FLOODPLAIN–PLAINS RIPARIAN WETLANDS

### Biological Diversity

- Riparian area structure and composition have changed due to irrigation diversions, reservoirs, farming, grazing, and human settlement. Consequently, some species diversity has been lost, and channel functions such as sediment transport have changed.
- Due to changes in larger river channel dynamics, many of the native fish species have been lost.

### Integrity and Resilience

- Riparian corridors have been interrupted due to grazing, agriculture, recreation, industrial, and urban uses, resulting in decreased wildlife corridors, increased water temperatures, increased sediment transport, and decreased transport of organic materials.
- Due to channel confinement and floodplain constrictions, peak flows have been frequently higher, velocity has been increased, and flood residence time has decreased, thus decreasing groundwater recharge.
- Disturbance due to flooding has been reduced below historic levels, resulting in decreased potential for regeneration of native species and reduced biomass production from native species. Channel

stability has also changed due to reduced vegetative cover and changes in sediment transport.

- Agricultural conversion, livestock grazing, invasion of exotic plants, structural alterations of habitats, pollution, and replacement of native cottonwood, willow, mesquite, and marshes by urban environments and croplands have influenced the availability of foraging, breeding, and wintering habitats and food resources for migratory birds. These impacts have also altered the composition, structure, and dynamics of plant and animal communities in riparian ecosystems.
- Increased presence of saltcedar has resulted in increasingly drier riparian systems. The salt residue in the leaf litter tends to prevent native plants from re-establishing. Dense saltcedar thickets form barriers to wildlife, livestock, and human access to water. Bird species richness and abundance in saltcedar-dominated communities are substantially lower than in native plant communities.
- The spread of saltcedar and other exotic woody ornamentals such as Russian-olive and Siberian elm has resulted in the creation of new plant communities with different vertical and horizontal layers, understory species composition, age class distribution, and mixes of native and exotic overstory species.

### Human Needs and Uses

- Use of riparian areas, such as grazing, recreation, agriculture, industrial, and urban uses has frequently resulted in water quality not meeting standards for designated beneficial uses.
- American Indian communities along the Colorado River and in northern Mexico have been concerned that their mesquite is not regenerating well enough to ensure sustained supplies for religious and commercial needs.

## CONCLUSION

The history of human occupation in the Southwest has resulted in many changes that are pervasive across all provinces. Many forest health issues are problems at scale levels below the province level. However, at a broad analysis resolution, we can address the following questions on the status of forest ecosystems:

### Is Adequate Provision Being Made for the Conservation of Biological Diversity?

Species numbers for many species that are intensively managed appear to be stable or even increasing. However, the population dynamics of many less intensively managed species are unknown; others are considered to be on the decline. Habitat fragmentation of the landscape appears to have increasingly isolated many plant and animal populations to the degree that their long-term viability is in question. As intensive human use of ecosystem resources increases with a corresponding rise in our population, the survival of these species will remain in doubt.

### Is Ecosystem Integrity and Resilience Being Maintained in the Long Term?

Generally, yes. However, in certain ecosystems such as deciduous riparian forests along major rivers, integrity and resilience has declined to a degree that seriously jeopardizes ecosystem structure and function. Similar degradation has occurred in coniferous woodlands (pinyon–juniper), where loss of understory plant cover has greatly accelerated soil erosion rates beyond historical levels. In coniferous forests (i.e., ponderosa pine), stand structure has changed to conditions that place these forests increasingly at risk of loss from catastrophic (stand replacement) fires relative to past time periods.

### Are Human Needs for Ecosystem Resource Use and Landscape Occupancy Being Adequately Accommodated?

Human population has been growing and human interest in and demands upon ecosystem resources have expanded and caused a significant rise in pressure upon the landscape. Increased human occupancy of the land has resulted in greater numbers of people being adversely impacted by disasters such as fires and floods. Increasing human presence upon and use of the land by a wide variety of groups often holding contrasting views and values concerning the land have resulted in a heightened degree of conflict. This is especially true between groups who favor traditional utilitarian uses of the land and those for which preservation and protection are highest priorities. Traditional extractive uses of land resources have declined, resulting in the closing of forest-based industries. American Indian tribes are speaking out more forcefully on traditional cultural and religious concerns. The clash of cultures, whether rural versus urban or utilitarian versus protection, appears driven by our inability to resolve issues related to balancing the needs and desires of humans with the biological needs of nonhuman organisms in the ecosystem. Thus, it seems that human needs are inadequately accommodated.

# CHAPTER 7: OPPORTUNITIES

"The world's ecosystems respond to the aggregate of both anthropogenic and natural stresses on their well-being, but our attempts to protect them are fragmented and unduly reductionist."
John Cairns, Jr. (1991)

On a broad scale, a blend of management styles across the landscape will be needed to accommodate human and landscape needs over time and space. For instance, the intensity of management in wilderness is typically lower than in non-wilderness to enhance recreational experiences. Some areas will be managed more intensively for commodity production to meet landowners' management objectives and resource demands. In determining the appropriate blend of management regimes at the landscape level, managers must consider the dynamics of the entire landscape; forest ecosystem health can be achieved only within the context of adaptive ecosystem management. This philosophy requires managers to integrate the biophysical and human dimensions of the landscape and restore ecosystem structure and processes essential to its integrity and long-term sustainability. The "Forest Service Ethics and Course to the Future" (USDA Forest Service 1994b) states that the national forests and grasslands will be managed as models of ecosystem management.

Forest health must be a priority in developing management actions. Ecosystems need not be returned to some pristine condition, but good management will create situations that are sustainable—that work with, not against the underlying processes (Allen and Hoekstra 1992). One of the Forest Service's national priorities is to restore or rehabilitate deteriorated ecosystems; the challenge is to translate national policy into on-the-ground management. Attempting to address all restoration needs is impossible. The continuing decline of personnel and budgets of land management agencies necessitates the setting of priorities of forest ecosystem health needs.

In establishing restoration priorities, both social concerns and ecological needs will need to be evaulated. Rather than exclusively targeting the most severely deteriorated ecosystems, it may be more cost-effective to focus restoration efforts on ecosystems that are at risk but only moderately degraded. Proactive management can head off further deterioration.

To make these determinations, the setting of forest health priorities must be an issue included in assessment efforts. One way this can be achieved within the Forest Service is through forest plans. Assessments of forest ecosystem health to support forest plan revision efforts should establish priorities for restoration needs for each forest. In addition, Ecosystem Management Areas (EMAs) at the landscape scale have been delineated for each forest in the Southwestern Region; the assessment of each EMA should include forest health priorities. Desired conditions for the EMAs developed in conjunction with each assessment should incorporate the concept of ecosystem health. Large area assessments at the regional or subregional scale are another opportunity to incorporate forest health needs into the planning process. Large area assessments provide the context for setting priorities at the forest plan level.

The assessment process includes the development of potential management practices that will incrementally move the landscape toward desired conditions for ecosystem health. Past and ongoing research studies and management restoration projects are invaluable in identifying innovative and practical techniques for reconstructing naturally functioning ecosystems. Several of the Region's ecosystem management demonstration projects have been partnerships efforts to restore pinyon–juniper ecosystems, e.g. the Carrizo Project on the Lincoln National Forest and the Flying V and H Project on the Tonto. Innovative pilot projects for road construction have led to a guidebook on managing roads for wet meadow ecosystem recovery (USDA Forest Service 1996b).

Restoration studies in ponderosa pine forests of the Southwest are ongoing at the land unit scale near Flagstaff, Arizona and are being initiated at the landscape scale in the Mount Trumbell Resource Conservation Area north of the Grand Canyon (Covington et al. 1997). New information that results form these and other restoration project activities needs to be synthesised and made widely available to land managers.

Information management is another area rich in opportunities. Ecosystem and adaptive management require data appropriate to the issues of the area and at the appropriate scale. The Southwestern Region has not developed data requirements to support forest ecosystem health assessments. The Region should review data requirements to see if appropriate information related to ecosystem health is being collected at the appropriate spatial scales. Where possible, ties to national efforts should be made. Often, projects stall because the information identified in the information needs assessment process is unavailable. This is particularly true for projects requiring information on the historic conditions of an area. The amount and quality of information on historic conditions is highly variable, and historic documents and inventories have limited value for reconstructing landscape appearance prior to minimal human influence (Kaufmann et al. 1994). Although it is useful to expand research of historic conditions from agency records, libraries, and other sources, it is necessary to develop that understanding of historic conditions using information which can be obtained within the time frame of the planned assessment.

New technologies have become available in data collection, modeling, and information transfer. Remote sensing data are being acquired nationally to support Forest Service activities, and other agencies have typically made their data available over the Internet. GIS technology is already being used by most land management agencies, although the data available to support GIS analysis is often lacking. Decision support systems for modeling alternative scenarios are currently being developed; the Forest Service has identified approximately 20 systems used within the agency, e.g., Spectrum, RELM, SNAP, EMDS. To coordinate activities across ownership boundaries, efficient communication between different parties is essential. Using computers to communicate via the Internet, videoconferencing, and satellite conferencing are technologies readily available today, but they are often inadequately used.

Ecosystem management integrates both the human dimension and the biophysical aspects of the ecosystem. Although the Forest Service, or any other entity, has limited knowledge of the ecological processes in ecosystems, the agency's greater weakness is understanding the social context of an ecosystem assessment. In forest ecosystem health assessments, the values and uses of the communities of place, communities of interest, and the public should be characterized. Traditional and cultural perspectives should be included. The public should be involved in the assessment process; innovative techniques to keep the public informed, such as posting information on the Internet, should be explored. Partnerships with various agencies and groups to accomplish mutually beneficial forest ecosystem health objectives should be pursued. The ability to initiate restoration projects is dependent on the level of support for the project, both internally and externally. At all levels of the Region (Regional Office, forests, and districts), the Forest Service needs to implement collaborative stewardship by aggressively pursuing opportunities to communicate and collaborate among themselves and with the public about forest ecosystem health issues.

Public land managers can work closely with environmental educators to promote forest health based on ecosystem sustainability. Roggenbuck and Driver (1996) identify several key aspects of a successful environmental education program. Public land managers must reach out and form partnerships with a wide variety of educators, including teachers at all levels of the school system, professors at univerisities, media leaders, and directors of zoos, museums, and art centers. Effective use of the news media (primarily radio, television, and newspapers) as an educational tool is critical to reach the large segment of the American public that does not visit public lands. It is also inportant to intensify our contact with the visting public by encouraging longer stays in forests and providing more frequent opportunitites (short loop hikes, for instance) to demonstrate forest ecosystem health practices and issues. We should also use our existing partners, e.g. outfitters, industry leaders, campground hosts, in environmental education workshops and to individually promote forest health. Focused opportunities for reaching young people, both in the classroom and in outdoor settings (field trips, residential camp programs) should be intensified.

The adaptive management approach views management as a learning experience. Management actions must be coupled with monitoring to evaluate ecosystem responses. Projects must specifically state objectives to establish monitoring needs at the onset of the project, not as an afterthought. Projects should not be initiated unless monitoring needs can be met. In determining monitoring needs, three types of monitoring should be considered: 1) Did the project do what it said it would do (implementation)? 2) Did it work (effectiveness)? 3) Were the assumptions that were made valid (validation)? Validation monitoring is often, but not necessarily, the role of research. After monitoring takes place, the results need to be scientifically evaluated and applied to successive projects in a continuous feedback loop. Learning from monitoring and evaluation is an important aspect of adaptive management, but it is not the only one. In active adaptive management, management determines knowledge gaps and deliberately initiates management experiments to fill in those gaps to better understand the complexities of ecosystems. Since there is an infinite list of potential management experiments, ones should be selected where the consequences are meaningful enough to justify the cost. In deciding what changes to try, managers should look at the importance of the problem, not at the certainty of the answer; and they should be committed to going on to other potential solutions if the first one tried is a "surprise." Surprising results are legitimate, not signs of failure. Experimentation requires a clear understanding of scientific methodology. It involves the development of hypotheses and quantifiable objectives, designing a sampling scheme, establishing control areas, and setting rules for deciding when to adjust management. Results of management experiments need to be widely disseminated to avoid duplication of effort and extend use of new knowledge. Active adaptive management may result in different research techniques being used than have been used in the past. The ideal design of a management experiment may not be the most rigorous design possible, since it may be impractical to implement. The need for research scientists to be part of this approach is obvious; they can provide expertise and guidance on experimental design, the process used to collect and interpret data, and methods for monitoring ecosystem responses. Therefore, a close collaboration with research is essential, as well as more effective technology transfer between management and science.

# CHAPTER 8: TOOLS TO ACHIEVE DESIRED RESULTS

"The only way to determine the most appropriate strategy for particular situations is for the manager to begin implementing natural experiments in the field." Unknown

This chapter presents a Forest Service perspective (that of the assessement team) on a general strategy for improving the long-term condition of the forests in Arizona and New Mexico at the forest and district level. The Forest Service has authority for stewardship of National Forest System land—maintaining habitat for wildlife species, providing recreational opportunities, and managing commodity uses; the U.S. Fish and Wildlife Service and state game and fish departments are responsible for managing species populations. The approach advocated in this report blends vegetation management, where and when appropriate, with natural forest processes. The best opportunity to maintain and improve forest soils, watershed conditions, recreation opportunities, wildlife habitats, indeed, all attributes of the forest ecosystem, is through sound vegetation management. Southwestern forests are indeed treasures; their management is both an art and a science.

There are many different ideas over what constitutes a healthy forest; opinions of how our federal lands should be managed differ even more. The strategy presented here is largely based on three premises which enjoy some general agreement (e.g., Sampson et al 1995):

1. Over the last century, there have been rather dramatic changes in the structures of Southwestern forests (Figure 8.1).

2. The demand for aesthetic values from Southwestern forests will continue to increase. People prefer to see large trees and open stands (Brown and Daniel 1984). Although they dislike views of dead and dying forests, people can appreciate the value of snags and top-killed trees for wildlife (Baker and Rabin 1988, Orland et al. 1992).

3. Even with greater conservation and recycling, there is an increasing local, national, and global demand for wood products.

We may never fully understand the complexities of ecosystems, but we know enough to manage Southwestern forests more appropriately than in the past. We have learned much from research, from the public, and from our past mistakes—and our successes! Over time, we will learn more and can adjust accordingly with adaptive management. Some of the suggestions presented here are already being practiced by Forest Service land managers.

Although historic conditions may not be "desired conditions" and may not be feasible to re-create over large areas, they do provide us much insight. There is a growing consensus that forests have become overcrowded and that there are too many small- and medium-size trees. Moreover, in some parts of the Southwest, there are few, old forests of large trees.

As discussed in preceding chapters, some past management, particularly fire exclusion, overgrazing, and high-grade logging, has led to unhealthy conditions in some areas. However, it is important for resource managers and the public to understand that other practices over the past century, including improvement selection cutting and the thinning of small trees, have not harmed and have probably improved the condition of the forest over time.

In discussing forest health among resource professionals and the public, we (the Forest Service) should accurately describe forest conditions and not overstate the case. Forests in some portions of the western United States have experienced dramatic episodes of tree mortality in recent years. For the most part, forests in the Southwest have remained green and appear healthy to many people.

**Figure 8.1 Ponderosa pine forests of the Southwest during the horse and buggy days was a grass matrix with individual, clumps, and stringers of large and variously-sized trees of almost exclusively ponderosa pine (see chapter 4).**

We should keep in mind, however, that the large-scale tree mortality seen elsewhere had occurred during or following extended periods of drought (Wickman 1992). Overall precipitation in the Southwest has been well above average the past couple of decades. But given the unprecedented tree densities throughout much of the Southwestern forests, what might happen during the next extended drought? Did the next drought cycle begin in 1996?

The following recommendations are the informed, professional judgements of the assessment team. Although the team believes these actions should be taken where and when appropriate, these recommendations are not policy statements directing managers to specific decisions. For the most part, these recommendations are compatible with guidelines recently developed for management of the northern goshawk and the Mexican spotted owl (Reynolds et al. 1992, USDI Fish and Wildlife Service 1995). They are primarily intended for ponderosa pine and mixed conifer forests, which make up the great majority of Southwestern forested lands. Spruce–fir ecosystems are thought to be relatively unaffected by past management; and for the most part, these forests appear to be in good condition and functioning normally. Sound management activities are appropriate in spruce–fir forests, but the majority of this forest type occurs in designated wilderness with limited management opportunities. Most of the recommendations discussed here, such as low thinning, also apply to pinyon–juniper woodlands, which have also been greatly affected by human activity. Recommendations for specific management situations, such as management of aspen and riparian areas, channel stabilization, recreation, exotic plants, and soil amendment, are also included.

## Density Management

The long-term condition of Southwestern forests can often be improved with prudent thinning. In most areas, the emphasis should be on "low thinning" or "thinning from below." Often, a combination of mechanical thinning and prescribed fire can be used to work toward a desired condition.

As in the past, thinning will include both commercial (sawtimber, pulp, and multi-product sales) and non-commercial treatments. The focus should be on removing smaller trees, and leaving a high proportion of the larger trees in most areas.

As a silvicultural term, "low thinning" means removal of trees from the lower crown classes. In some locations, this can simply involve removal of trees from the understory (Smith 1962); but in many areas it can involve removal of some overstory trees as well. Suppressed, intermediate, and often some co-dominant trees are cut; dominant and at least some co-dominant trees are left. Simply stated, the largest trees are left, and other trees are thinned as appropriate. This approach is described as focusing on what is left (the residual) instead of what is cut (the removal). In many respects, low thinning is the opposite of high grading in which the best trees are removed first and the inferior trees are left.

Prudent thinning has numerous benefits. The growth rate of the remaining trees usually improves significantly. Obtaining large trees is a function of time and site productivity, but also of competition. Similarly, by reducing competition, the longevity of the oldest and largest trees may increase (Barclay and Layton 1990). A more open canopy allows better growth of grasses, forbs, and shrubs, which, in turn, helps maintain forest soils. Some insect and disease damage can be averted, and the risk from fire reduced. The long-term appearance of the forest can be enhanced—possibly the greatest benefit of all, at least from a human perspective.

Well-thinned, relatively open areas scattered across the landscape, interspersed with denser, less intensively managed areas, would provide a wide array of wildlife habitat, and would be a forest less prone to large-scale catastrophic wildfire. There are some documented cases where large wildfires have behaved as non-destructive ground fires as they moved into thinned forests (Barbouletos and Morelan 1995).

Many thinning projects in the past, especially non-commercial thinning of young stands, achieved rather uniform spacing, resulting in a "tree-farm" appearance. Spacing should be highly variable to favor the best trees and provide more heterogeneous conditions.

Good selection of residual trees is a simple practice that should be done to counter the effects of past high grading. Terms like "crop-tree selection," developed for timber production, can have much broader application; trees can be selected as future wildlife snags. Selection and marking greatly affect the outcome of treatments and, ultimately, what the forest will look like long into the future.

Thinning by hand (cutting, chopping, grubbing) is a useful tool due to its selective nature and minimal ground disturbance. However, since it has a high labor cost per acre, it is usually suitable for initial treatment of small trees in light to moderate densities or in areas where mechanical treatments with heavy equipment are not acceptable.

Within timber sale areas, to return stand densities to the level of historic variability, it will be necessary to remove at least 90 percent of the volume in the form of small trees, those less than 18 inches dbh (see Figure 5.10). Guidelines should allow flexibility to account for site differences and conditions, but in most areas the majority of the larger trees should be left.

An aggressive program for thinning small-diameter trees is required to reduce stand densities. Much progress in this area would be achieved if the majority of the Knutson-Vandenberg (K-V) funds generated by most timber sales were used for thinning. Additional sources of funding and channelling as much existing funding as possible into thinning dense, small-diameter stands would further improve the condition. Thinning small-diameter trees will either require a non-commerical entry or market development.

If sawtimber were harvested at a sustainable growth rate, acreage of pulpwood harvest and small-diameter thinning were increased, and prescribed burning activities were greatly increased, there should be significant improvements in forest conditions within a few decades.

If we take this approach (and explain what we are doing), we are apt to gain more widespread public support. Over time, this should lead to greater efficiency in developing and implementing projects, and, ultimately, more rapid progress in restoring forest ecosystem health.

Efforts to improve forest conditions could be assisted by the development and application of new technologies in the Southwest, including the manufacture of engineered wood products and the biomass industry. Creating new markets for the vast amounts of pulpwood and other small-dimension material available in the Southwestern Region could be more aggressively pursued.

The agency hopes that the increased attention on forest health, both nationally and regionally, will allow more flexibility and help alleviate budgetary constraints. Some forest health treatments will be below-cost in the short term but, considering long-term values of forests, both commodity and non-commodity, will be sound investments. Forest condition and commodity products need to be equally weighted.

## Even-aged vs Uneven-aged Management

True even-age management has seldom been practiced in the Southwest. The great majority of stands, including most of those that have received silvicultural treatment in the last 20 years, contain multiple age and size classes. Thus, articulation of the use of even-aged management regimes in the forest plans is somewhat inaccurate and, in some respects, self-defeating.

The terms "even-aged" and "uneven-aged" are scale-dependent, relative to the size of the area, and may not be the best terminology (Bradshaw 1992). Generally, a better approach is to work with and enhance existing stand conditions rather than to rigidly adhere to an idealized system.

## Combination Silvicultural Methods

Both even-aged and uneven-aged silviculture have application and often can be used in combination. For example, when group selection is chosen for certain objectives, it is often appropriate to use low thinning between the groups to achieve a wider array of benefits.

Individual tree selection has some important advantages over group selection. Selection of individual trees to be left after harvesting can improve stand quality and genetic tree quality. Growth rates typically increase throughout a stand after individual-tree selection thinning, whereas only trees on the edges of the groups (or within groups if some were removed) show any release. Species composition can be manipulated with either method, but with individual-tree selection, this can often be accomplished more directly. For example, the proportion of ponderosa pine can be increased in many mixed conifer forests by selecting white fir and Douglas-fir for removal. Also, basal area can be lowered to encourage pine regeneration. Stand susceptibility to bark beetles can often be lowered using individual-tree selection or by group selection augmented with thinning between groups.

As discussed previously, more open conditions achieved by low thinning can reduce susceptibility to wildfire, and can make it more feasible (i.e., less risky) to reintroduce fire with prescribed burning. In some instances, however, open conditions can make it more difficult to execute a prescribed fire. On the other hand, group selection which opens a canopy more than individual selection often provides more heterogeneity in stand structure and increases habitat diversity. Similarly, the openings created usually encourage the development of grasses, forbs, and shrubs. These effects can be achieved, although to a lesser degree, by varying spacing with single-tree selection. Group selection can also be used to regenerate shade-intolerant species like ponderosa pine and aspen.

Damage to the remaining trees from felling or skidding is usually less using group selection, although in most areas damage can be minimized with either method (Figure 8.2). Road densities needed for management are probably similar for both methods. Individual tree selection is an ineffective method for long-term control of dwarf mistletoe. Group selection appears to have promise in this respect because of the "groupy" spatial distribution of the parasite; however, in most cases regeneration within the openings will be exposed to infected trees on the edges of the group (or reserve trees left within the groups).

## Slash, Woody Debris, and Snags

Timber harvest and other forest thinning typically generates large quantities of slash and thereby creates numerous problems. Non-commercial thinning of dense stands can result in very high fuel loads, making the sites hazardous in wildfire or prescribed fire. Fresh slash, particularly in ponderosa pine forests, can lead to rapid buildups of bark beetle

**Figure 8.2** Even large-sized material can be handled with horse and small-equipment; these heritage methods may still be useful for operating at low cost and without damage to the soil and and residual trees.

populations, especially *Ips* species, which may then attack and kill green standing trees. To reduce this potential, thinning is best carried out from July to December (ideally in mid- to late summer), allowing the slash to dry out and making it less favorable for the beetles (Parker 1991). Lopping and scattering is recommended for some sites, particularly when thinning is done in the spring. This practice hastens drying of the slash and generally improves the appearance of a site, although it increases treatment costs. Public fuelwood gathering can reduce the amount of green slash, reducing both fuel loading and the chance for beetle outbreaks. Large slash piles also have a visual impact.

Although large amounts of slash can create problems, it is becoming evident that coarse woody debris has great importance for forest soils and wildlife habitat. Management recommendations, using ectomycorrhizae as indicators, have been developed for forests in the Rocky Mountains (Harvey et al. 1987, Graham et al. 1994). These suggest leaving roughly 10 to 15 tons per acre of coarse woody debris after timber harvesting to maintain long-term productivity. Some ponderosa pine sites may require less material, whereas some mixed conifer and spruce–fir sites may benefit from larger amounts.

Snags, essential habitat for many species, including cavity-dependent species, are deficient in many forested areas. Rigorous efforts in the past to fell dead trees to remove ignition sources, as well as efforts to harvest declining trees before they die, are largely responsible for snag deficiencies. These policies have been modified in recent years; over time, we can expect to have higher snag densities in forests.

Although not recommended as a widespread practice, snag recruitment may be appropriate on some sites (Figure 8.3). For example, large, dwarf

**Figure 8.3** **Most wildlife cavities are constructed in the decayed wood of old-growth trees. Second-growth trees, even while still alive, can be inoculated with wood-decay fungi to accelerate their developement into desirable wildlife trees. In this experimantal demonstration project, a hole is drilled into the upper bole of a large tree, a plastic pipe is inserted (to retard wound closure), and the tree is inoculated with a wooden dowel.**

mistletoe-infected trees might be selectively killed to make snags in areas where significant amounts of young regeneration can be protected from infection.

## Salvage

Although often linked with the forest health issue, salvage is primarily an economic activity. Salvage sales supply wood to mills and benefit local economies; but they generally do little to improve forest conditions, except for reducing fuel loading. However, K-V funds can and should be used to pay for non-commercial thinning, tree planting, prescribed fire, and other restoration treatments. Salvage operations need to be done in a way that minimizes soil damage and loss, and leaves an adequate number of standing snags and fallen logs.

## Prescribed Fire

Significant increase in the use of prescribed fire is needed in appropriate areas on Southwestern forests. Prescribed fires can be natural or management-ignited. In most parts of the Southwest and until very recently, prescribed fire has mostly been used to burn slash piles and for small broadcast burns. An increase in the number of acres of broadcast burning would enhance forest health.

The potential benefits from broadcast burning are numerous and include—reduction in fuel loads; stimulation of understory vegetation including grasses, forbs, and shrubs; thinning of overcrowded stands; and nutrient cycling. Over time, prudent use of prescribed burning could reduce the damage caused by wildfire, as well as the costs associated with fire suppression (Moody et al. 1992).

Thinning stands with fire can potentially be done at a much lower cost than with mechanical thinning, although past attempts to do this in the Southwest have met with varying degrees of success (Harrington and Sackett 1990). Generally, fire increases structural heterogeneity and diversity, creating mosaics within stands and over larger areas. It recycles nutrients for use by surviving trees and new vegetation. No other silvicultural technique fully mimics the ecological effects of historical fire regimes.

Burning tends to promote natural regeneration of ponderosa pine, providing favorable seedbeds and enhancing the growing environment for survival (Harrington and Sackett 1990). Repeated burning of the same area is expected to maintain a sparse understory and relatively open forest conditions by killing some of the previously established regeneration.

A few studies indicate a tendency for understory burning to reduce stand dwarf mistletoe infection levels (Harrington and Hawksworth 1990); significant amounts of crown scorch are probably needed to achieve this effect.

One of the obstacles to more widespread use of broadcast burning in the Southwest is the risk involved both to resources and property. In many forests, fuel loads are so high that prescribed burning alone could lead to stand-replacement fires. These areas need to be mechanically thinned first, with much of the cut stems removed from the site, before fire can be safely reintroduced. One of the other risks is to old-growth trees; their protection may require either removing accumulated duff, protecting the trees and surrounding duff with foam, or establishing a fire-line around them.

Broadcast burns are recommended following most mechanical thinning operations on ponderosa pine and lower mixed conifer sites. Generally, such fires should be designed to reduce fine fuels, leave coarser fuels, and cause minimal damage to the remaining stand. As with any prescribed burn, timing is critical. Occasionally, stands may benefit from understory burns prior to mechanical thinning, to reduce ground fuels before the additional slash is generated.

Because of crown scorch and needle fall after understory burning, fuel loads can increase to high levels within a year or two after treatment. Thus, reburns are often needed to reduce these fuels.

Burning intervals appropriate for various forest types, based on current knowledge of natural fire history (Table 4.1), are:

| | |
|---|---|
| Pinyon–juniper | 10–30 years |
| Ponderosa pine | 2–10 years |
| Xeric mixed conifer | 5–12 years |
| Mesic mixed conifer | 20–25 years |
| Spruce–fir | usually not recommended |

Like other management practices, prescribed burning is both an art and a science. Every prescribed burn can be a learning tool; the acquired experience of practitioners is invaluable. Documentation and monitoring of prescribed burning activities and their effects is also be crucial for developing and improving burning programs.

### Smoke Management

Fires within forested ecosystems naturally create smoke. Smoke is or can be hazardous to those who live near burn areas, either wildfires or prescribed fires. Smoke entering the atmosphere can create hazards through visibility reductions and, in some cases, increase breathing difficulties for individuals. Smoke can also create "smoke odors" inside of homes. For individuals living within the wildland/urban interface, visible smoke clouds can also create mild or intense apprehension and fear for safety and property.

Because of smoke concerns, some are opposed to fire of any kind, including management-ignited fires or those naturally started through lightning. Often when fuels reduction proposals are made within the wildland/urban interface, opposition is raised during public meetings, through an appeals process, or some means of litigation. Long delays can result while fire hazard continues to increase. As the urban interface continues to grow and expand, opposition to smoke-related activities is expected to increase.

Prescribed natural fire programs are often acceptable to large segments of rural population areas as long as the "smoke duration" is relatively short. Smoke is normally tolerated if the event doesn't exceed 10 to 14 days. After this period of time, the tolerance level declines rapidly. Individuals living within larger population centers are less tolerant to smoke from any source. Despite these concerns, people should recognize that all forests will eventually burn whether management-ignited or as wildfires.

Currently the Environmental Protection Agency (EPA) guidelines for smoke emissions are based upon PM-10 standards (particulate matter exceeding 10 microns). Current standards for air quality are a maximum of 150 micrograms/cubic meter of air. EPA is now studying the possibility of adopting a PM-2.5 standard. Since approximately 70 percent of the particulate emissions from fire are less than 2.5 microns in diameter, the standards proposed by EPA will provide significant challenges to the Forest Service and other users of prescribed fire.

In implementing forest health strategies, it will be important to increase the amount of aceage that can be treated for fuels reduction. The current proposal for fuels reduction projects nationally is 3,000,000 acres per year by the year 2000.

### Insect and Pathogen Considerations

Extensive tree decline and mortality from insects and pathogens are often equated with an unhealthy forest. At the same time, dead and dying trees are important components of healthy forest ecosystems. Because the effects of forest insects and pathogens have often been and should be considered in the development of management practices, we include a brief discussion and some general recommendations in this area.

It may be useful to consider high levels of forest insect or disease activity to be an indicator of an unhealthy condition (Bennett et al. 1994). Typically, they would indicate overcrowded conditions, or, sometimes, unusual or unnatural changes in species composition.

Ecologically, some insects and pathogens appear to act as regulators of forest condition, i.e., nature's response, via feedback mechanisms, to restore previous conditions or ecological balance. In extreme cases, this process can lead to socially undesirable consequences such as large-scale tree mortality followed by catastrophic fire.

Generally, emphasis in managing forest insects and pathogens should be on prevention rather than direct suppression. Some strategies to prevent *Ips* beetle problems were discussed previously. Thinning can limit mortality from other bark beetles in many forest situations (Fiddler et al. 1995, Schmid and Mata 1992); it appears to be a way of preventing unacceptable damage on specific sites and, presumably, across landscapes. Thinning in mixed conifer forests, particularly where ponderosa pine can be retained, may well lessen the severity and impact of unsightly spruce budworm outbreaks.

Dwarf mistletoes present a difficult situation that should be recognized in efforts to maintain or improve forest health. Fairly aggressive efforts to control these parasites in the 1980s generated much controversy and opposition. Nevertheless, decades of research indicate that a rather aggressive approach is required for effective control in some situations (Heidmann 1983, Beatty 1986, Hawksworth and Johnson 1989). Regenerating stands and creating openings at least 20 acres in size are needed to provide effective, long-term control where infestation is severe.

Low thinning and prescribed burning may be the best ecological approach for managing dwarf mistletoes on many ponderosa pine and mixed conifer sites. It is probably best to defer many heavily infested stands from treatment. Occasionally, on recently regenerated sites, it is prudent to remove all sources of infection. In some cases, this may involve the creation of fairly extensive openings. Specific recommendations for dwarf mistletoes should be based on the characteristics of individual sites, considering the surrounding landscape.

Some sites may need to be managed in consideration of the effects of root diseases. Thinning may increase the incidence of root disease on some sites; however, this has seldom been a significant problem in the Southwest. Management recommendations tend to be very site-specific (Hagle and Goheen 1988).

Efforts should continue to limit the potential for white pine blister rust to spread to other parts of the Southwest. Working with natural host resistance may be the best approach for reducing its impact in the Sacramento Mountains. Removing diseased trees through salvage or thinning will have little value, since infection of pine occurs through an alternate host. Large-scale salvage logging of white pine might reduce genetic variation in the host population.

## Treatment Priorities

In general, treatment priorities should be established, not by focusing on where the biggest problems are (as is often suggested), but by where the greatest improvements can likely be achieved, at a reasonable cost. For example, it usually makes more sense to thin a middle-aged forest that has been thinned within the last 20–30 years than one of similar age that has never been thinned and is severely stagnated. Thinning healthy ponderosa pine stands is often more beneficial than thinning dwarf mistletoe infested stands. However, the removal of infected seed trees or residuals in newly regenerated areas should be given a high priority on many sites.

Areas where healthy ponderosa pine can be favored over fir are often excellent candidates for thinning. Inter-planting with site-compatible pine has merit, particularly on some previously logged mixed conifer sites. Creating open parklike stands of ponderosa pine should be a priority for some areas. In some locations, this could be done with one or two heavy thinnings. On other sites, it could be done gradually, using a series of treatments over 20 years or more.

Sampson et al. (1995), in a discussion of the condition of national forests throughout the inland West, eloquently states:

> "These lands, so highly important for so many reasons, to so many people, deserve better care than we have been willing—as a public—to give them... If we continue to spend all our time in preparing studies and fighting over whether or not to address these treatment needs, the natural forces such as wildfire will take those decisions out of our hands..."

As part of the Southwestern Region's Forest Health Restoration Initiative (USDA Forest Service 1993b), 742,000 acres in Arizona and 583,000 acres in New Mexico, were recommended for treatment over a 5-year period. The Initiative suggests this be accomplished by increasing the use of prescribed fire, reducing fire hazard in wildland/urban interfaces, and pursuing as much small-diameter thinning as possible, consistent with overall forest health.

### Aspen

Unlike conifers, aspen has a strong tendency to be self-thinning, mostly due to a number of fungal diseases. Moreover, because this species is very susceptible to wounding and subsequent introduction of pathogens, thinning is usually not recommended (Jones and Shepperd 1985, Hinds 1976). However, sapling-size aspen (less than four inches dbh) can usually be thinned without much damage to the remaining trees (Jones and Shepperd 1985) to provide small products such as latillas (i.e., small diameter roundstock used in the ceiling and roofing of traditional Southwestern homes).

A major decrease in aspen type suggests an urgent need for treatments to regenerate the species. Group selection cuts, small clearcuts which fit into the landscape, or, in some areas, prescribed fire, can be used to regenerate aspen. Although aspen readily resprouts following such treatments, grazing, browsing, and trampling by both wildlife and livestock can be a serious problem in establishing regeneration. Fencing is needed in many areas. Aspen can be regenerated and promoted by reducing populations of browsing animals, at least temporarily. Removal of "invading" conifer understories is suggested as a way of maintaining aspen and may be appropriate for some areas. However, the effects of such treatment is typically short-lived. Moreover, unlike low thinning in pine or mixed conifer forests, which largely mimics the effects of fire, the removal of conifer understories from aspen stands does not resemble natural processes.

### Riparian Areas

Grazing pressure from ungulates (cattle and elk) can be reduced within degraded areas, on a site-by-site basis. Enclosures (fencing) used where appropriate and for a long enough period protect plant cover, facilitate regeneration, and prevent damage to stream banks and channels. In the long term, however, we should strive for conditions where fenses are not needed. Generally, any tree cutting within a riparian area would be very selective, and appropriate road construction and channel diversions would be designed to minimize adverse effects. Where opportunities exist, developed recreation sites can be moved out of sensitive riparian areas. Good riparian restoration minimizes use of structures and relies more on vegetation recovery.

### Channel Stabilization

The goal of channel stabilization is to achieve a long lasting effect with vegetation. Mechanical measures are used to supplement or accelerate stabilization, but they are not the best, long-term approach. Bed control measures, using nonporous or porous structures, are generally used to stop bed erosion or headcuts upstream. Bank treatments such as armor, flow deflectors, or flow separators stop or reverse lateral bank erosion. Flow separation structures, used only where the river system has a floodplain wide enough to allow for sediment deposition, yield the greatest benefit for riparian ecosystems (DeBano and Schmidt 1989). It may be necessary to partially or totally reconstruct a channel to meet desired geomorphic characteristics. Good channel design maintains smooth transitions of flow at all points upstream and downstream. Vegetation recovery is the key to channel stabilization.

### Recreation Tools

Proper recreation facilities are designed to minimize resource damage. Reclamation of damaged areas (for instance, mine tailings) are a high priority in areas of visual interest. Annual hazard tree surveys identify trees with safety hazards for subsequent trimming or removal. Areas highly impacted by dispersed use, such as hunting camps, can be hardened by having their boundaries marked or fenced to prevent further expansion and reducing the number of fire pits. Desired trails are monitored and maintained; those that have been poorly designed requre closing and reconstruction.

## Exotic Plants

Management of exotic plants, especially those designated as noxious weeds, is essential to maintain ecosystem health, particularly within forest grasslands and riparian areas. Even with strategic planning and project implementation, the expansion and spread of aggressive weeds will continue. Management and treatment of exotic plants is and will continue to be a never ending process. As a first step, all noxious weed infestations are identified and mapped. Risk assessments are performed and used as a baseline for monitoring. Integrated weed management programs and plans are developed and implemented (with appropriate NEPA analysis) to address situations prior to infestations getting further out of control. Control efforts must be designed to protect native vegetation, achieve desired conditions, and maintain biodiversity. Management areas are designed to treat infested ecosystems regardless of jurisdictional boundaries. To facilitate this process, memorandums of understanding (MOU) with other federal and state agencies, county governments and private landowners can be developed and implemented.

## Soil Amendment Techniques

Scattering slash and woody debris is used to add nutrients to the soil, as discussed previously. Research on the use of fertilizer to improve the status of nutrients and plant growth has shown mixed results. Fertilizers should be limited to sites where an analysis indicates a nutrient deficiency and where soil moisture conditions are favorable. The application of treated municipal sludge as a soil amendment is becoming more popular, although opportunities to use sludge may be limited by its availability. Sludge has been tested in New Mexico where it has been used successfully to reduce runoff and improve plant growth (Aguilar and Loftin 1992).

# CHAPTER 9: RESEARCH NEEDS

Although there is an adequate scientific basis to justify the need for maintaining and restoring healthy forests, numerous information gaps remain in the understanding of Southwestern ecosystems, application of techniques, and assessment of cultural and social values. Evans (1997) presents the conclusions of a review and workshop to identify research needs for management of National Forest lands in the Southwest. That effort categorizes research needs and current work into four priorities: 1) inventory, monitoring, and assessment; 2) ecosystem health, disturbance, and restoration; 3) wildlife habitat relations with emphasis on TES; and 4) human needs and values. Many of the information gaps identified in Evans (1997) relate directly or indirectly to forest ecosystem health issues and concerns described in the previous chapters of this assessment. The following research needs are those specifically identified by the assessment team as critical for implementing adaptive management to maintain and restore forest ecosystem health in the Southwest.

## UNDERSTANDING HISTORIC VARIABILITY

Improved information concerning reference conditions for Southwestern forests is needed, specifically the historical ranges and rates of change of numerous ecosystem variables. Information which characterizes ecosystem composition, structure, and function through time, including the frequency, intensity, duration, and spatial patterns of disturbance at multiple scales is fundamental. This information provides managers with a better understanding of the historic variability of these complex ecosystems. This historic variability should be described both in terms of mean (central tendency) and variation (dispersion). Models can present this information in graphical form similar to normal distribution curves (histograms) and display the frequency with which these systems remain near average status or deviate toward extremes under slowly or rapidly changing conditions. Such information contributes to improving our overall understanding of the dynamic behavior of these ecosystems in the absence of human disturbance and management.

In view of the substantial changes brought about in Southwestern forests by European settlement, an improved understanding of ecological succession, as modified and influenced by these changes, is needed. In ecosystems that have undergone significant change or degradation, successional pathways have been altered and plant communities are currently proceeding along trajectories for which no historical analog exists. The ultimate result of such successional change is largely unknown. A better understanding of this dynamic change is crucial to the success of ecological restoration and efforts to achieve desired conditions in the ecosystems of the future.

A much improved working model of forest ecosystems in the Southwest is needed, one which explains dynamic behavior across multiple levels of the ecological hierarchy. The basic ecological building blocks of genes, genotypes, and species need to be functionally integrated with populations, communities, and landscapes to more fully identify emergent system properties characteristic of each forest ecosystem. Numerous modeling approaches could be used to achieve this integration, including individualist models, process models, and spatial models. Just the exercise of constructing such models should provide improved insights into the mechanisms which influence ecosystem behavior such as decomposition, nutrient cycling, growth and development, patch dynamics, and species dispersal and migration.

Even though humans have been an integral component of the Southwestern landscape for over 12,000 years, the archaeological and paleoenvironmental record of human habitation is often sparse and fragmentary. It is generally recognized that humans have significantly affected ecosystem conditions within the last century, but little is known about the impacts of prehistoric cultures on the landscape. Additional research is needed to better understand the interactions of prehistoric cultures and forest ecosystems through time.

## UNDERSTANDING FOREST ECOSYSTEM HEALTH

Ecological variables which serve as appropriate indicators of ecosystem health are needed. These variables must be affordable, measurable, and reliable indicators of the health status of the ecosystem.

Whether these variables are structural or functional characteristics, a reference database that describes acceptable (i.e., normal) and pathological (i.e., abnormal) ranges for each greatly enhances the utility of such measurements. Models which improve managers' understanding of species populations and trends, patch dynamics, disturbance effects, and human interactions need to be developed. Comparative analyses of the effects of wildfire and prescribed fire on resource values, air quality, and human health are also needed.

## UNDERSTANDING INSECT AND PATHOGEN INTERACTIONS

More needs to be learned concerning how landscapes and ecosystems, under various management regimes, are affected by and respond to insects and pathogens at different temporal and spatial scales. Better hazard rating and damage prediction models need to be developed that describe the effects of insects and pathogens in a manner readily understandable by agency personnel and members of the public.

The most critical needs vary by ecosystem and insect or pathogen. In woodland and riparian ecosystems, we need an inventory of potentially harmful insects and pathogens, their effects on various resource values, and in particular the effects of dwarf mistletoe on pinyon nut production. We need to know how thinning may prevent *Ips* beetle outbreaks in woodland ecosystems or reduce the susceptibility of mixed conifer forests to western spruce budworm. For southwestern white pine, we need reliable estimates for the rates of spread and intensification of blister rust and levels of natural resistance to blister rust. We need to quantify the effects of uneven-aged management on the spread and intensification of dwarf mistletoe in ponderosa and mixed conifer forests. Information is lacking on the causes of aspen regeneration dieback and how to prevent it.

## UNDERSTANDING WILDLIFE HABITAT REQUIREMENTS

Information concerning the habitat requirements of TES species is needed, (e.g., the Mexican spotted owl). Models which address the needs of multiple wildlife species would also be highly useful. These should include provisions for the influences of climate, competition, predation, and disturbance on community niche sizes and overlaps.

The scales at which each wildlife species are best managed and the habitat components that influence each species and group at each scale need to be identified. A better understanding of the influence of management practices on ecological processes at multiple scales is also needed. This information allows managers to ascertain the effects of management applied at one scale upon other scales and determine where to optimally apply management for the most desirable results across the hierarchy.

In the interest of maintaining viable wildlife populations, information concerning the spatial distribution of habitat necessary for unimpaired movement of populations and individuals is needed. Information relevant to the effects of size, shape, and juxtaposition of patches and corridors on specific species and communities is essential. Critical population thresholds that threaten viability need to be determined. Specific data types relevant to the determination of species viability needs to be added to habitat relationship databases. And finally, quantifiable data are required on effects of bark beetle outbreaks to TES species populations and habitat.

## DEVELOPING TECHNIQUES TO RESTORE AND MAINTAIN ECOSYSTEMS

Additional research is required in several areas before an improved understanding of forest ecosystems can be implemented. In particular, these areas include use of prescribed fire, wood utilization of small trees, and weed detection and control. Information is needed to ensure safe and effective use of prescribed fire in fuel reduction and vegetation management. Equipment technologies for economical harvesting of small trees (3 to 4 inches dbh) needs to be developed or imported from other regions and adapted to Southwestern conditions. Economic markets for small trees, such as poles and posts, chip-and-saw, chips, pressure composites, and pulp need to be developed. New product development in cooperation with the Forest Products Laboratory in Madison, Wisconsin, may be helpful in this matter. Work is needed in the detection of exotic plant infestations and the evaluation of the efficacy of mechanical, chemical, biological, and natural control methods.

## CULTURAL AND SOCIAL ASSESSMENTS

A better understanding of the cultural context for forest health is needed. Improved insight into public perceptions concerning what constitutes a healthy forest and what kinds and levels of management activities are acceptable is essential, as well as a better understanding of the expectations of forest visitors and users. Better models for tribal consultation and a better knowledge base for evaluating historic and contemporary traditional uses is important to facilitate collaborative partnerships. A greater understanding of the effects of various recreational activities on forest health, especially in riparian ecosystems, is also crucial.

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# GLOSSARY

**Acequia**: an irrigation ditch or channel, a term commonly used in northern New Mexico.

**Adaptive management**: a process for implementing policy decisions as an ongoing activity that requires monitoring and adjustment. Adaptive management applies scientific principles and methods to improve resource management incrementally as managers learn from experience and as new scientific findings and social changes demand.

**Allopathy**: an interaction between plant species in which one species inhibits the establishment or growth on the second species through production of a selectively inhibitory chemical agent.

**B.P.**: before present.

**Biotic community:** a group of interacting organisms within a given area. Plant communities are characterized by a distinctive physiognomy or appearance, such as woodland or forest. At a regional scale, the biotic community is called a biome (e.g., the western coniferous forest biome).

**Biodiversity:** the variety of life and its processes. Biodiversity includes the diversity of landscapes, communities, and populations (genetic variation). Also called biological diversity or biotic diversity.

**Biotic integrity**: the ability of a community to recover and maintain system processes within historic variability.

**Browsing**: the consumption by livestock and wildlife of leaves and shoots from woody plants. See grazing.

**Catastrophic**: a property of non-linear dynamic systems (such as biotic communities) in which what appears to be a small disturbance (introduction of an exotic species) initiates large changes and establishes a new set of stable conditions (see Jameson 1994).

**Cienega**: a Southwestern, non-forested wetland. Cienegas are dominated by graminoids and may be seasonally dry.

**Climax**: the state of a biotic community attained when constituent species populations fluctuate rather than exhibit successional replacement and thereby self-perpetuate as long as climatic, edaphic, and biotic conditions continue.

**Community of interest**: a social group that shares common perspectives, vulnerabilities, and preferences with respect to resource management issues (e.g., hunters, anglers, permittees, and environmentalists).

**Community of place**: a social group bounded by geographic locality.

**DBH**: diameter at breast height, a measure of tree diameter determined at the standard height of 4.5 feet.

**Dendrochronology**: the technique of dating events with use of tree rings.

**Disturbance**: a discrete event or process which kills or removes vegetation. From an ecological and hierarchical perspective, disturbance is a change in the minimal structure of an ecosystem caused by a factor external to the reference structure (see Pickett et al. 1989).

**Dwarf mistletoes**: plants of the genus *Arceuthobium* (Viscaceae). Dwarf mistletoes are shrubby, aerial parasites of gymnosperms, distinguished by hydrostatically explosive fruits and sticky seeds.

**Ecological approach**: a method of natural resource planning and management that provides due consideration for the interrelationships between all species, including humans, and their environment.

**Ecological assessment**: a process for describing the status of ecosystems, their components, related processes and effects, and associated interactions. An ecological assessment should address social, cultural, and political issues relevant to resource management and use scientifically supportable data.

**Ecoregion**: a continuous geographic area over which the macroclimate is sufficiently uniform to permit development of similar ecosystems on sites with similar geophysical properties. Ecoregions contain multiple landscapes with different spatial patterns of ecosystems.

**Ecosystem:** a complex of interacting plants and animals with their physical surroundings. Ecosystems are isolated from each other by boundaries which confine and restrict the movement of energy and matter; for example, an ecosystem could be recognized at a watershed scale by designating an area of common drainage (i.e., topography determines movement of water).

**Ecosystem function**: the processes through which the constituent living and nonliving elements of ecosystems change and interact. The term ecological function is often used in reference to the role or specific contribution of a entity to system behavior.

**Ecosystem management**: a concept of natural resources management wherein human activities are considered within the context of economic, ecological, and social interactions within a defined area or region over both the short and long term. Its purpose is to meet human needs while maintaining the health, diversity, and productivity of ecosystems.

**Ecosystem restoration**: actions taken to modify an ecosystem for the purpose of re-establishing and maintaining desired ecological structures and processes.

**Ecosystem structure**: the physical elements and spatial arrangement of the living and nonliving elements within an ecosystem.

**Ecosystem sustainability**: the capacity of an ecosystem for long-term maintenance of ecological processes and functions, biological diversity, and productivity. Also called ecological sustainability.

**Endangered species**: any species that is in danger of extinction throughout all or a significant portion of its range.

**Exotic species**: a non-native or non-indigenous species, usually introduced as the result of human activities.

**Fire hazard:** the fuel complex defined by kind, arrangement, volume, condition, and location that form a special threat of ignition or suppression difficulty.

**Forage**: food for livestock and wildlife, especially taken by browsing or grazing.

**Forb**: an herbaceous plant other than a graminoid.

**Forest health**: a condition wherein a forest has the capacity across the landscape for renewal, for recovery from a wide range of disturbances, and for retention of its ecological resiliency, while meeting current and future needs of people for desired levels of values, uses, products, and services.

**Forest**: in general, an area or biotic community dominated by trees of any size (usually, at least 10 percent of the area is covered by trees). If distinction is made to woodlands, forests are composed of taller, more closely-spaced trees.

**Fragmentation**: a process by which large, contiguous blocks of habitat are broken into smaller patches isolated from each other by a landscape matrix dissimilar to the original habitat.

**Fuels:** the organic materials that support ignition and spread of a fire (duff, litter, grass, weeds, forbs, brush, trees, snags, and logs).

**Fuel treatment**: the re-arrangement or disposal of fuels to reduce the fire hazard.

**Fuelwood**: the round, split, or sawed wood of general refuse material, which is cut into short lengths for burning as fuel.

**GIS**: geographic information system, a computer-assisted method for organizing, analyzing, and displaying spatial data.

**Graminoid**: a grass or grass-like plant.

**Grazing**: the consumption by livestock and wildlife of range or pasture forage. Although strictly grazing refers to consumption of forbs and graminoids, it is often used in a general sense to include both grazing and browsing.

**Habitat**: the natural environment of a plant or animal; the locality where an organism may generally be found and where the essentials of its survival and reproduction are present. Habitats are typically described by geographic boundary, biotic community, or various physical characteristics.

**Habitat type**: the collective term for all land areas potentially capable of supporting the same climax, biotic community.

**Healthy ecosystem**: an ecosystem in which structure and functions allow the desired maintenance over time of biological diversity, biotic integrity, and ecological processes.

**Hierarchical**: a description of ecosystems referring to their nested and scale-dependent organization. See Allen and Hoekstra (1992).

**High-grading**: a harvesting practice in which the most valuable trees are removed with little provision for regeneration or subsequent entries.

**Historic variability**: the variation in spatial, structural, compositional, and temporal characteristics of ecosystem elements during a reference period prior to intensive resource use and management. In the Southwest, this reference period is typically considered the recent climatic and ecological era before the Territorial period (resource use and management by native and Hispanic cultures are integrated with other ecological process).

**Homeostasis**: the maintenance of a steady state by use of feedback control processes. In homeostatic systems, a change outside the normal range is seen as a decline in the health of that system.

**Human dimension**: an integral component of ecosystem management that recognizes people are part of ecosystems; that people's pursuits of past, present, and future desires, needs, and values (including perceptions, beliefs, attitudes, and behaviors) have and will continue to influence ecosystems; and that ecosystem management must include consideration of the physical, emotional, mental, spiritual, social, cultural, and economic well-being of people and communities.

**Indicator:** a quantitative or qualitative variable which can be measured or described and which when observed periodically demonstrates trends. Ecosystem indicators track the magnitude of stress, habitat characteristics, exposure to the stressor, or ecological response to exposure.

**K-V Act**: Knutson-Vandenberg Act of 1930 which established a funding mechanism for wildlife and fisheries, timber, soil, air, and watershed restoration and enhancement projects. Projects are restricted to timber sale areas and are funded from receipts generated on those areas.

**Landscape:** a heterogeneous area composed of a cluster of interacting ecosystems that are repeated in similar form throughout the area. Forest landscapes of the Southwest usually range from hundreds to thousands of acres and are the result of geologic, edaphic, climatic, biotic, and human influences.

**Life zone**: a broad class of vegetation and climatic condition based on temperature and precipitation. Merriam's (1898) life zones in the Southwest include the Hudsonian, Canadian, and Transitional (from cool wet to warm dry; terms are nominal rather than specifically geographic).

**Malpais:** a Southwestern term for rough country underlain by basaltic lava.

**Management scenario**: a description of future conditions expected to result from the general implementation of a broad resource management strategy. Management scenarios are developed to explore the biological and social implications, tradeoffs, and uncertainties of ecosystem management rather than present a range of options for site specific adoption (management alternatives).

**Monitoring**: the component of adaptive management in which information is collected to track system behavior and its response to management.

**NEPA**: National Environmental Protection Act.

**Nonstocked**: a site condition in which the area is less than 10 percent stocked with live trees.

**Noxious weed**: a plant species that possesses one or more of the following attributes — aggressive and difficult to manage, poisonous, toxic, parasitic, a carrier or host of serious insect or disease and being native or new to or not common to the United States or parts thereof.

**OHV**: off-highway vehicle.

**Old growth**: a late stage of forest succession. Although the specific characteristics of old-growth stands vary with species composition and history, some commonly expected attributes in mesic forests on productive sites include —an abundance of large trees at least 180 to 200 years old; a multi-layered, multi-species canopy dominated by large overstory trees with moderate to high closure; numerous trees with broken tops, snags, and large logs.

**Paleobotany**: the study of lake sediments, pollens, and microfossils to determine ancient climate and vegetation.

**Phreatophyte**: a deep rooted plant that obtains its water from the water table.

**Prescribed fire (or burning)**: the intentional burning of forest fuels under conditions specified in an approved plan to meet management objectives and confined to a predetermined area; ignition may be either the result of a scheduled management activity or from other sources (e.g., lightning).

**Province**: an ecological unit at the regional scale of assessment controlled mainly by continental weather patterns.

**Resilience**: the ability of an ecosystem to maintain or restore biodiversity, biotic integrity, and ecological structure and processes following disturbance.

**Riparian ecosystem**: a transitional ecosystem located between aquatic (usually riverine) and terrestrial (upland) environments. Riparian ecosystems are identified by distinctive soil characteristics and vegetation communities that require free water.

**Rhizomorph**: a highly differentiated, fully autonomous, apically growing aggregation of hyphae produced by a few fungal species. Rhizomorphs of Armillaria resemble black "shoestrings" and function in extension of the fungus to new substrate.

**Ruderal**: plant species adapted to sites with recent disturbance. Some characteristics of ruderal species are — a potentially high relative growth rate during the seedling phase, early onset of flowering, self-pollination, rapid maturation and release of seeds, and sustained seed production at expense of ability for competition and tolerance to stress.

**RVD**: recreation visitor day. A recreation visitor day is use of a site or area for 12 visitor-hours, aggregated as 1 person for 12 hours, 12 persons for 1 hour, or any equivalent combination of continuous or intermittent use.

**Salvage harvest**: removal of dead and dying trees resulting from insect and disease epidemics or wildfire.

**Sapling**: a tree 1 to 4.9 inches DBH.

**Scale**: the degree of resolution from a spatial or temporal perspective at which ecological processes, structures, and changes across space and time are observed and measured.

**Sediment**: solid material, both mineral and organic, that is in suspension, being transported, or has been moved from its site of origin by air, water, gravity, or ice.

**Seedling**: a tree less than one inch DBH.

**Sensitive species**: those plant and animal species identified by a Regional Forester for which population viability is a concern as evidenced by: (a) significant current or predicted downward trends in population numbers or density; or (b) significant current or predicted downward trend in habitat capability that would reduce a species' existing distribution.

**Sere**: a transitional stage in plant succession. Environmental conditions, species, or biotic communities may be described as **seral** in contrast to climax.

**Slash**: debris such as logs, bark, branches, and stumps left after logging, pruning, thinning, brush cutting, or windstorms.

**Snag**: a standing dead tree from which the leaves and fine branches have fallen.

**Soil productivity**: the capacity of a soil, in its normal environment, to produce a specific plant or sequence of plants under a specific system of management.

**Stability**: a condition whereby system variables return to equilibrium after being disturbed. Stability within ecosystems results from various population feedback mechanisms and integration of disturbances at larger spatial scales (see DeAngelis and Waterhouse 1987).

**Stand**: a biotic community, particularly of trees, possessing sufficient uniformity of composition, age, and spatial arrangement to be distinguishable from adjacent communities. Stand structure refers to the composition, age, and arrangement of the trees in a delimited biotic community.

**Stand density index**: a relative measure of competition in a forest stand based on number of trees per unit area and average tree size.

**Stewardship**: caring for land and associated resources and maintaining healthy ecosystems for future generations.

**Succession**: the ecological process of sequential replacement by plant communities on a given site as a result of differential reproduction and competition.

**Sustained yield**: the perpetual output of a renewable resource, achieved and maintained at a given management intensity, without impairment of the productivity of the land.

**TES**: threatened, endangered, or sensitive species. Also, Terrestrial Ecosystem Survey.

**Thinning**: the silvicultural practice of removing selected trees in a stand to reduce competition for light, water, and nutrients and thereby promote the growth and survival of remaining trees.

**Threatened species**: any species that is likely to become an endangered species with the foreseeable future through all or a significant portion of its range.

**Watershed**: an area of land with a characteristic drainage network that contributes surface or ground water to flow at a designated location; a drainage basin or a major subdivision of a drainage basin.

**Woodland**: an area or biotic community dominated by widely-spaced trees of short stature growing on warm, dry sites. In the Southwest, common woodland species are oak, pinyon, and juniper; these woodlands usually occur below 8,000 feet elevation.

# COMMON AND SCIENTIFIC NAMES

## PLANTS

| Common Name | Scientific Name |
|---|---|
| alligator juniper | *Juniperus deppeana* Steud. |
| Apache pine | *Pinus engelmannii* Carr. |
| Arizona fescue | *Festuca arizonica* Vasey |
| Arizona pine | *Pinus arizonica* Engelm. |
| Arizona singleleaf pinyon | *Pinus californiarum* subsp. *fallax* (Little) D.K. Bailey |
| Arizona sycamore | *Platanus wrightii* S. Wats. |
| Arizona walnut | *Juglans major* (Torr.) Heller |
| Arizona white oak | *Quercus arizonica* Sarg. |
| arroyo willow | *Salix lasiolepis* Benth. |
| aspen | *Populus tremuloides* Michx. |
| bigtooth maple | *Acer grandidentatum* Nutt. |
| blue grama | *Bouteloua gracilis* (Kunth) Griffiths |
| blue spruce | *Picea pungens* Engelm. |
| Bonpland willow | *Salix bonplandiana* |
| border pinyon | *Pinus discolor* D.K. Bailey & Hawkws. |
| box-elder | *Acer negundo* L. |
| broom snakeweed | *Gutierrezia sarothrae* (Pursh) Britt. & Rusby |
| Chihauhua pine | *Pinus leiophylla* Schiede & Deppe var. *chihuahuana* (Engelm.) G.R. Shaw |
| corkbark fir | *Abies lasiocarpa* (Hook.) Nutt. var. *arizonaica* (Merr.) Lemmon |
| coyote willow | *Salix exigua* Nutt. |
| Douglas-fir dwarf mistletoe | *Arceuthobium douglasii* Engelm. |
| Emory oak | *Quercus emoryi* Torr. |
| Engelmann spruce | *Picea engelmannii* Parry ex Engelm. |
| Fremont cottonwood | *Populus fremontii* S. Wats. |
| Gambel oak | *Quercus gambelii* Nutt. |
| Goodding's black willow | *Salix gooddingii* C. Ball |
| gray oak | *Quercus grisea* Liebm. |
| Junegrass | *Koeleria macrantha* (Ledeb.) J.A. Schultes |
| Mexican blue oak | *Quercus oblongifolia* Torr. |
| mountain muhly | *Muhlenbergia montana* (Nutt.) A. Hitchc. |
| mutton grass | *Poa fendleriana* (Steudel) Vasey |
| narrowleaf cottonwood | *Populus angustifolia* James |
| netleaf oak | *Quercus reticulata* Humb. & Bonpl. |
| New Mexico locust | *Robina neomexicana* A. Grey |
| New Mexico needlegrass | *Stipa neomexicana* (Thurb.) Scribn. |
| one-seed juniper | *Juniperus monosperma* (Engelm.) Sarg. |
| pinyon | *Pinus edulis* Engelm. |
| pinyon ricegrass | *Piptochaetium fimbriatum* (H. B. K.) Hitchc. |
| quaking aspen | *Populus tremuloides* Michx. |

| | |
|---|---|
| Rocky Mountain Douglas-fir | *Pseudotsuga menziesii* (Mirbel) Franco var. *glauca* (Mayr) Franco |
| Rocky Mountain juniper | *Juniperus scopulorum* Sarg. |
| Rocky Mountain ponderosa pine | *Pinus ponderosa* Doug. ex Laws. var. *scopularum* Engel. |
| Rocky Mountain white fir | *Abies concolor* (Gord. & Glend.) Hildebrand var. *concolor* |
| Russian-olive | *Elaeagnus augustifolia* L. |
| saltcedar | *Tamarix ramosissima* Ledeb. |
| Scouler willow | *Salix scouleriana* Barratt |
| Siberian elm | *Ulmus pumila* L. |
| silverleaf oak | *Quercus hypoleucoides* A. Camus |
| southwestern dwarf mistletoe | *Arceuthobium vaginatum* (Willd.) Presl subsp. *cryptopodum* (Engelm.) Hawksw. & Wiens |
| southwestern white pine | *Pinus strobiformis* Engelm. |
| squirreltail | *Elymus elymoides* (Rafin) Swezey |
| subalpine fir | *Abies lasiocarpa* (Hook.) Nutt. |
| sugar pine | *Pinus lambertiana* Dougl. |
| Utah juniper | *Juniperus osteosperma* (Torr.) Little |
| velvet ash | *Fraxinus velutina* Torr. |
| wavyleaf oak | *Quercus undalata* Torr. |
| western wheatgrass | *Pascopyrum smithii* (Rydb.) A. Löve |
| western white pine | *Pinus monticola* Dougl. ex D. Don |
| whitebark pine | *Pinus albicaulis* Engelm. |

## FUNGI

| | |
|---|---|
| annosus root disease | *Heterobasidion annosus* (Fr.) Bref. |
| schweinitzii butt rot | *Phaeolus schweinitzii* (Fr.) Pat. |
| tomentosus root rot | *Inonotus tomentosus* (Fr.) Gilbn. |
| white pine blister rust | *Cronartium ribicola* Fisch. |

## ANIMALS

### Insects

| Common name | Scientific name |
|---|---|
| Arizona fivespined ips | *Ips lecontei* Swaine |
| fir engraver | *Scolytus ventralis* LeConte |
| Douglas-fir beetle | *Dendroctonus pseudotsuga* Hopkins |
| mountain pine beetle | *Dendroctonus ponderosae* Hopkins |
| pine engraver | *Ips pini* (Say) |
| red-spotted purple | *Basilarchia astyanax* |
| roundheaded pine beetle | *Dendroctonus adjunctus* Blandford |
| spruce beetle | *Dendroctonus rufipennis* (Kirby) |
| western balsam bark beetle | *Dryocoetes confusus* Swaine |
| western pine beetle | *Dendroctonus brevicomis* LeConte |

| | |
|---|---|
| western spruce budworm | *Choristoneura occidentalis* Freeman |
| western tent caterpillar | *Malacosoma californicum* (Packard) |
| western tiger swallowtail | *Papilio rutulus* Lucus |

## Fish

| | |
|---|---|
| Apache trout | *Salmo apache* Miller |
| channel catfish | *Ictalurus punctatus* (Rafinesque) |
| Gila trout | *Salmo gilae* Richardson |
| Little Colorado spinedace | *Lepidomeda vittata* Cope |
| loach minnow | *Tiarogo cobitis* Girard |
| rainbow trout | *Salmo gairdneri* Richardson |
| Rio Grande cutthroat trout | *Salmo clarki* Richardson |
| Sonoran chub | *Gila ditaenia* Miller |
| spikedace | *Meda fulgida* Girard |

## Birds

| | |
|---|---|
| brown-headed cowbird | *Molothrus ater* |
| ferruginous pygmy owl | *Glaucidium brasillianum* |
| Mexican spotted owl | *Stris occidentalis lucida* |
| northern flicker | *Colaptes auratus* |
| northern goshawk | *Accipiter gentilis atricapillus* |
| southwestern willow flycatcher | *Empidonax trailii extimus* |
| wild turkey | *Meleagris gallopavo* |

## Mammals

| | |
|---|---|
| beaver | *Castor canadensis* |
| bighorn sheep | *Ovis canadensis* |
| bison | *Bison bison* |
| black bear | *Ursus americanus* |
| elk | *Cervus elaphus* |
| gray wolf | *Canis lupus* |
| grizzly | *Ursus arctos* |
| javelina | *Tayassu tajacu* |
| Merriam's elk | *Cervus elaphus merriami* (extinct) |
| mountain lion | *Felis concolor* |
| mule deer | *Odocoileus hemionus* |
| pronghorn | *Antilocapra americana* |
| spotted bat | *Euderma maculataum* |
| white-tailed deer | *Odocoileus virginianus* |

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